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BASIN RANGE STRUCTURE AND STRATIGRAPHY OF THE WARNER RANGE NORTHEASTERN CALIFORNIA

BY

RICHARD JOEL RUSSELL

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STRATIGRAPHY OF THE WARNER RANGE
NORTHEASTERN CALIFORNIA

BY

RICHARD JOEL RUSSELL, 1895-

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BASIN RANGE STRUCTURE AND STRATIGRAPHY OF THE WARNER RANGE, NORTHEASTERN CALIFORNIA

BY
RICHARD JOEL RUSSELL

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INTRODUCTION

In three recent papers Louderback¹ has reviewed the controversy which exists in regard to the origin of Basin ranges and has presented many concrete facts in favor of an origin by means of faulting, accompanied by little or no folding, at a rather recent date in geological time. In reviewing this controversy it is apparent that a large part of it has its basis in the confusion of the results of an early period of folding with those of a much later period of normal faulting. Selecting an area in which both of these periods of crustal deformation are present Louderback² clearly demonstrated that these two periods of

¹ Louderback, G. D., Univ. Calif. Publ. Bull. Dept. Geol. Sci., Basin Range structure in the Great Basin, vol. 14, no. 10, 1923; Period of scarp production in the Great Basin, vol. 15, no. 1, 1924; Morphologic features of the Basin Range displacements in the Great Basin, vol. 16, no. 1, 1926.

² Louderback, G. D., Basin Range structure of the Humboldt region, Bull. Geol. Soc. Am., vol. 15, pp. 289-346, 1904.

activity are separated and unrelated and that the Basin ranges as they exist today have characters and features depending primarily upon the later period, the period of normal faulting.

In northwestern Nevada and northeastern California there is an extensive territory which is particularly favorable for the study of Basin Range structure because all of the rocks exposed were essentially horizontal prior to the period of deformation which outlined the existing ranges. This fact was pointed out by Russell³ many years ago. It is curious that one of the most vigorous opponents⁴ of the fault-block hypothesis of Basin Range structure attempted to pass over this region by means of the naïve statement that "our knowledge of the ranges of northwestern Nevada is comparatively slight, since in this region volcanic rocks are so abundant that nearly everywhere they mask the structure, which itself is rather complicated." As a matter of fact the volcanic rocks of this region are for the most part extensive sheets lying concordantly, one above the other, bent or broken only in relation to comparatively recent Basin Range faulting. Thus we here find "the simplest type of Basin Range structure."⁵

The Warner Range is centrally situated in the area just described. Because of its structural and topographic simplicity it was selected as the basis of the Basin Range study here presented.

From the study of the Warner Range and the adjacent territory to the extent of fifty or sixty miles on either side, the conclusion is drawn that the hypothesis of origin by means of block faulting accords most closely with observable facts.

FIELD WORK AND ACKNOWLEDGMENTS

The writer became interested in the geology of Modoc County, California, in the summer of 1920 when he first visited that area as a member of the Alexander Great Basin Expedition. In the company of Professor Chester Stock he spent several weeks in the vicinity of Alturas and later crossed the Warner Range. At that time it was recognized that the range presents an interesting example of Basin Range structure and also that from the standpoint of correlating the vertebrate faunas on its east and west sides it would be desirable to know more of its stratigraphy.

³ Russell, I. C., U. S. Geol. Surv., Fourth Ann. Rept., p. 443, 1884.

⁴ Spurr, J. E., Origin and structure of the Basin ranges, Bull. Geol. Soc. Am., vol. 12, p. 225, 1901.

⁵ Louderback, G. D., Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 16, p. 3, 1926.

During the summers from 1922 to 1925, the equivalent of three full field seasons of three months each was spent in the Warner Range, or in its vicinity. In the course of this field work Messrs. Maurice B. Schmittou, Norman B. Hardy, and Peveril Meigs III acted as assistants, one summer each. To these three gentlemen the writer is indebted for untiring helpfulness and many practical suggestions. Mr. Schmittou became particularly interested in the petrography of some of the lavas of the range, working his results up into a Bachelor's thesis, which is on file in the Department of Geology of the University of California.

Throughout the period of field work and of preparation of this report the writer has worked under the direction of Professor George D. Louderback, of the University of California, and has found in him a source of constant inspiration, constructive criticism, and helpfulness. He is also indebted to Dr. Louderback because of a personal visit the latter made to the Warner Range during the season of 1924.

The topographic base used for the map of areal geology is adapted from a map furnished by the Forest Service, of the United States Department of Agriculture.

It is a pleasure to acknowledge the cooperation and assistance rendered by the staff of Modoc National Forest, particularly that of Mr. William Brown, Assistant Supervisor. Valuable suggestions and assistance have been received from the following persons and are gratefully acknowledged: Professors Holway and Sauer, Department of Geography, Professors Buwalda and Hulin, Department of Geological Sciences, University of California; Mr. Fred Bush, of Cedarville; Mr. William E. Dorris, of Alturas; and, for the loan of surveying equipment, the Department of Geography and the Department of Mining, of the University of California.

Professor Chester Stock, Dr. Ralph W. Chaney, and Mr. Frederick Frost have each, at one time or another, made one or more visits to the Warner Range, their interests being paleontologic. From each of them the writer has received many helpful suggestions.

GEOGRAPHY

LOCATION AND EXTENT

The Warner Range is situated in the northeastern corner of California. With the meridian of $120^{\circ} 15' W$ as its approximate axis, the range lies across the eastern end of Modoc County for 58 miles but, as indicated on the index map (fig. 1) it extends north some

distance into Oregon and south into Lassen County, California, and slightly into Nevada. The entire axial length of the range is about 87 miles but no precise value can be given because its terminations are not clearly defined. At the north the mountainous unity of the range is very gradually lost in mergence with the high plateau between Abert Lake and Warner Valley. A similar transition at the southern end of the range, as represented on the index map, unites it with high plateaus just east of Madeline Plains. The width of the range in its

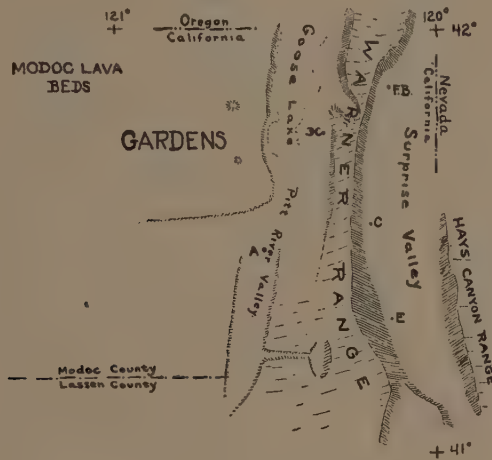


Fig. 1. Index map.

A, Alturas; C, Cedarville; DC, Davis Creek; E, Eagleville; FB, Fort Bidwell.

typical portion, in Modoc County, varies from about 8 to 20 miles, the narrowest portion lying slightly north of Alturas, the county seat. Toward the plateaus the range widens rapidly.

The portion of the range areally mapped lies almost entirely within the limits of Modoc County. The Modoc-Lassen County boundary line practically forms the southern limit of the mapped territory, and Fandango Valley, about 11 miles south of the Oregon line, was the northernmost area mapped. With an average width of about 11 miles and a length of about 47 miles the mapped area covers about 500 square miles of mountainous territory.

Most of the Warner Range is shown on the Alturas, California, Quadrangle of the United States Geological Survey. Its southern extensions appear on the Long Valley, Nevada, Quadrangle. The southern plateaus appear on the Honey Lake, California, and Granite Range, Nevada, sheets. The northern extension of the range does not at present appear in the quadrangles of the Topographic Atlas but a rough map of it has been made by Mr. G. A. Waring and pub-

lished in Water Supply Paper 220, 1908. The Forest Service base map used by the writer was made by Mr. S. N. Stoner. In addition to being more recent and more accurate than the Alturas Quadrangle it possesses the advantages of larger scale and smaller contour interval.

The larger part of the Warner Range lies strictly in the Great Basin, as shown by Russell⁶ in his map of that area. Defining the Great Basin as an area drained by streams which fail to reach the ocean, the boundary passes along the crest of the southern and central portions of the range. In the latitude of the southern end of Goose Lake the boundary turns westward so that Goose Lake and the northern portion of the range lie within the Great Basin. On the Alturas Quadrangle the impression is given that Goose Lake drains southward into the North Fork of the Pitt River. This impression is essentially erroneous for while a comparatively fresh outlet channel exists, it has been used, in draining the lake, for only three or four hours since the first settlement of Modoc County by whites.

The highest peaks in the Warner Range lie southeast of Alturas. These just fall short of attaining the elevation of 10,000 feet above sea level. As the elevations of the valleys both east and west of the range are less than 4,700 feet the maximum local relief is somewhat over 5,000 feet. Summit elevations of 10,000 feet, however, are not characteristic of the range as a whole, 8,000 feet being more nearly the average. Thus the average local relief is somewhat greater than 3,000 feet. About one-third of the area of the range attains an elevation of at least 7,000 feet.

PLACE NAMES

Many of the names used on the Alturas Quadrangle have little or no meaning to the people of Modoc County. The names used on the maps made by the Forest Service approached local usage more closely but even these contained many mistakes in spelling as well as many obsolete or unknown place names. An additional difficulty was encountered in that a rather large synonymy exists in local popular usage, particularly arising from differing usages on the two sides of the range. In order to clarify matters it was felt advisable to make a list of synonymous names.

Because of the fact that a single name may be used to designate several entirely different features, as for example the name "Mill Creek," which is used for three different streams in the portion of

⁶ Russell, I. C., U. S. Geol. Surv., Fourth Ann. Rept., pl. 83, 1884.

the Warner Range within the boundaries of Modoc County, it has been felt necessary to use supplementary place names in order to give an additional clue as to the particular geographical feature referred to—thus “Lake City Mill Creek” is the Mill Creek which flows past Lake City and “Buck Mountain South” is the more southerly of the two Buck Mountains.

In the following list names used in this report are printed in *italics*. These are the most widely used names as far as could be discerned. The complete synonymy is given only once for each feature, immediately after the name here adopted.

Alkali lakes, *Surprise Valley Lakes*.

Bald Mountain, Bald Peak. Cedar Peak of Alturas Quadrangle incorrect.

Bald Mountain is one and one-half miles north of Cedar Peak.

Bare or Bare's, *Bear*.

Bear Creek, Bare Creek, Bare's Creek. (After Bear family.)

Bear Mountain, Bare Mountain, Horse Mountain, South Emerson Butte.

Brush Lake, *Hidden Lake*.

Buckhorn Mountain, Hat Mountain (one of three), Lost Lake Mountain, Silver Peak.

Buck Mountain, Warren Peak. See also *Buck Mountain South*.

Buck Mountain South, Buck Mountain (Buckhorn Mountain and Hat Mountain incorrect), south of Patterson Mill and west of *Buckhorn Mountain*.

Cedar Peak, Little Bald Mountain (not Little Baldy), Cedar Mountain. See note *Bald Mountain*.

Cold Peak, Cole Peak, Powers Butte.

Cole Peak, *Cold Peak*.

Cooley Cañon, *Franklin Cañon*.

Eagle Peak, Eagle Mountain, Saddleback. *Saddleback* includes two summits of which *Eagle Peak* is the southern.

Fish Lake, *Hidden Lake*.

Franklin Cañon, Cooley Cañon, Swearinger Cañon, Swedrengen Cañon.

Hat Mountain, either *Buck Mountain South* or *Buckhorn Mountain*.

Hays Cañon Range, the range east of Surprise Valley south of Cedarville.

Hidden Lake, Brush Lake, Fish Lake, Lost Lake (incorrect), South Emerson Lake, Trout Lake.

Horse Mountain, *Bear Mountain*.

Jess Valley, Jesse Valley.

Lake Jess, the lake which once filled Jess Valley.

Lake Surprise, the old lake which once filled Surprise Valley.

Little Bald Mountain, *Cedar Peak*.

Lost Lake on Emerson Creek, *Hidden Lake* (*Lost Lake* is on *Silver Creek*).

Lost Lake Mountain, *Buckhorn Mountain*.

Mill Creek South flows through *Clear Lake* into *Jess Valley*.

New Pine Creek (stream), *Pine Creek North*.

Pine Creek, *Pine Creek North*, *Pine Creek South*.

Pine Creek South flows through *Pine Creek Basin*.

Pit River, *Pitt River*.

Powers Butte, *Cold Peak*.

Saddleback, the double mountain of which *Eagle Peak* is the southern culminating summit.

Silver Peak, *Buckhorn Mountain*.
South Emerson Butte, *Bear Mountain*.
South Emerson Lake, *Hidden Lake*.
Surprise Valley Lakes, Alkali Lakes, Upper-Middle-Lower Lakes.
Swearinger Cañon, *Franklin Cañon*.
Swedrengen Cañon, *Franklin Cañon*.
Trout Lake, *Hidden Lake*.
Tom Creek, Thom Creek, Thoms Creek, Toms Creek.
Warren Peak, *Buck Mountain*.

TOPOGRAPHY

The Warner Range is a long and comparatively narrow orogenic block similar in many respects to the vast majority of mountain ranges in the Great Basin. It is meridional for the greater part of its length and is sharply defined from adjacent valleys on the basis of abrupt slope changes. Few Great Basin ranges approach it in the matter of topographic or structural simplicity. It is an uplifted block having a length about eight times greater than its width.

To the east, toward Surprise Valley, the range presents a bold steep front which "considered from the artist's standpoint . . . compares favorably with the western slope of the Wahsatch Mountains, and is certainly far grander than the majority of desert ranges in Utah and Nevada."⁷

The crest line above the bold Surprise Valley front is fairly even, particularly when seen in distant view as from the summits of the Hays Cañon Range, east of Surprise Valley. On closer inspection one finds that aside from local variations in crest-line elevation, resulting chiefly from differential erosional causes, there are also more or less systematic variations on a larger scale due to differential uplift. Generally speaking, elevations are greater toward the south and lesser toward the north, but the highest point on a meridional profile is not at the extreme southern end but north about one-fifth of the length of the range from that point. Eagle Peak, the highest point on the crest, lying eight miles north of the Modoc-Lassen county boundary line, attains an elevation of almost 10,000 feet. South of Eagle Peak there is a rapid change in crest line elevation to a general elevation of about 7,000 feet, with a few culminating summits reaching as much as a thousand feet higher. Toward the southern plateaus there is further reduction in elevation, the change being quite gradual when considered on a large scale but taking place by means of numerous abrupt steps. For about seven miles north of Eagle Peak, crest line

⁷ Russell, I. C., *op. cit.*, p. 449.

elevations quite commonly exceed 9,000 feet, the northern end of this high region being Buck Mountain, rising to an elevation of 9,722 feet. North of Buck Mountain the central part of the range culminates in crests generally less than 8,000 feet high but Payne Peak, Cedar Peak, and Bald Mountain rise above that elevation. From Bald Mountain to Fandango Pass maximum elevations are generally in the neighborhood of 7,500 feet, beyond the pass Mount Bidwell, commanding Surprise Valley at its northern end, rises butte-like to an elevation of 8,225 feet. Beyond this conspicuous summit the crest lowers gradually into the plateau which forms the continuation of the range in Oregon.

In the entire distance of approximately eighty-five miles along the crest there are but two deeply cut notches. The southern notch, generally known as Cedar Pass, between Payne Peak and Cedar Peak, has determined the location of the main highway across the range, the Alturas-Cedarville road. At its summit the road attains the elevation of 6,450 feet. The northern notch, Fandango Pass, is used by the only other automobile road crossing the range in Modoc County. This road connects Willow Ranch, in Goose Lake Valley, with the town of Fort Bidwell, in Surprise Valley. The elevation of Fandango Pass is approximately 6,200 feet.

The slope from crest to base along the Surprise Valley front is quite uniformly steep. The average gradient from the summit of Eagle Peak to the nearest margin of Surprise Valley is 1,400 feet per mile. From the summit of Buck Mountain the gradient is 1,225 feet per mile. In the central part of the range, at Bald Mountain, it is 1,180. North of Fandango Pass the gradient steepens, reaching a maximum on the eastern slope of Mount Bidwell at a rate of 2,280 feet per mile.

Two elements are discernible in the slope of the Surprise Valley front, an upper element of rather gentle slope and a lower element of steeper slope. Generally the upper element is much longer than the lower element. In a surveyed section across Cedar Peak (fig. 2) it will be noted that the break between the two elements occurs about 16,500 feet east of the crest and that the slope length of the lower element is about 5,000 feet. The profile, thus divided, indicates an average slope of 5° for the upper element and 18° for the lower. In the section surveyed across Cold Peak the upper element has a length of about 11,500 feet and a slope of about 15° while the 2,500 foot lower element slopes about 30° . Less accurate values giving similar results may be obtained by taking profiles from the Forest Service

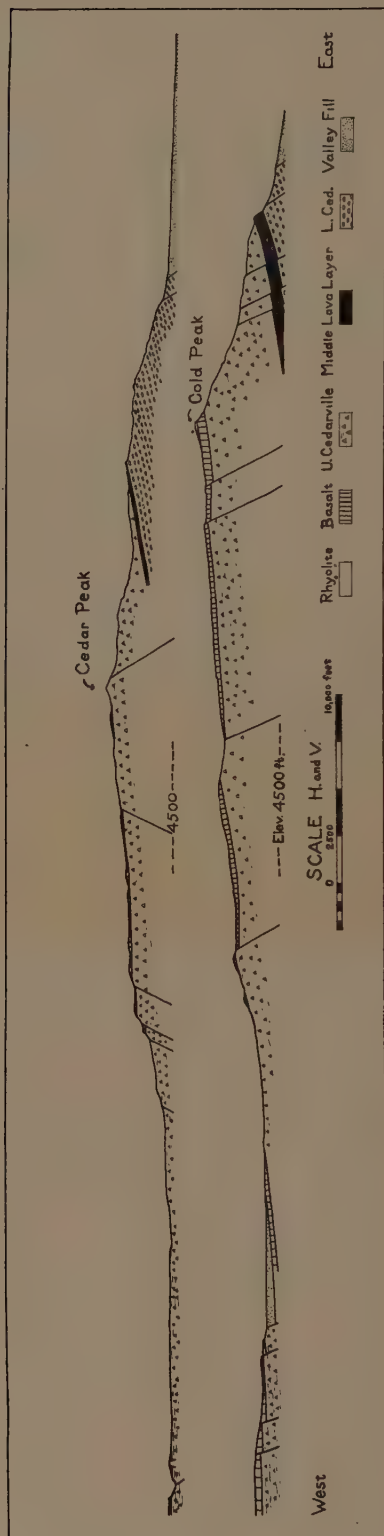


Fig. 2. Geological sections across the Warner Range.

topographic map at practically any point along the Surprise Valley front. The break between the two elements is shown in figure 3.

The upper element of slope profiles is divisible into two portions, a long typical portion and, toward the crests, a shorter oversteepened portion. The long typical portion is characterized by topography well adjusted to structure. As the structure is that of beds of differing resistance dipping rather gently away from the front, or westward, the topography consists for the most part of benches gently dipping toward the range and separated by cliffs at the more resistant layers. The frequency of alternation of these two topographic types depends upon the relative thicknesses of the layers concerned and

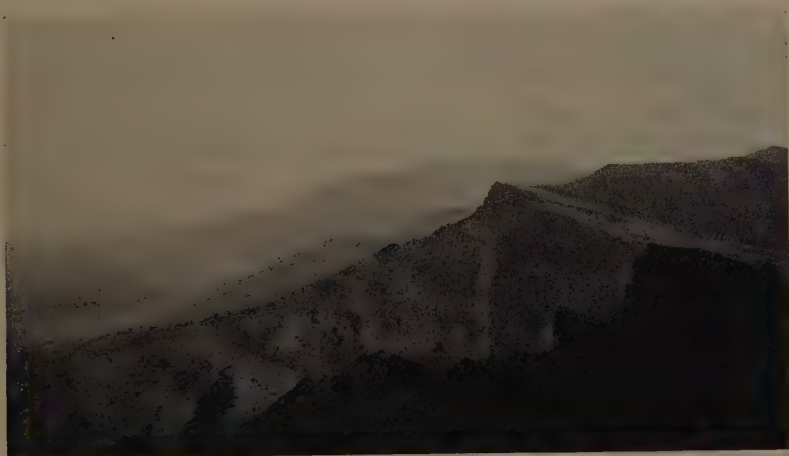


Fig. 3. The Surprise Valley front in the vicinity of Cedarville, looking south.

varies from place to place. Toward the crests adjustment to structure is less common. Here extremely steep slopes are encountered, vertical cliffs several hundred feet high in some instances. The oversteepening has in part been caused by rather recent glaciation, there being several well preserved cirques, some containing lakes, at high altitudes. Rapid weathering, due to frost action, and the presence of several agencies eager to carry away weathered fragments seem to be chiefly responsible for the oversteepened zone, the rôle of glaciation being clearly subordinate.

The lower element of slope profiles consists of a typical portion and an oversteepened base. Adjustment to structure is in its infancy in the typical portion. Through the agency of differential erosion small benches separated by low cliffs are starting to form but rain falling upon this surface is rapidly concentrated in steep gullies which follow direct courses across resistant and non-resistant beds alike.

This is in sharp contrast to the subsequent drainage of the typical portion of the upper profile element. The oversteepened base of the lower element is much shorter than the typical portion and is usually separable on the basis of an abrupt change in slope angle. Little or no erosional evidence of underlying structure is found on its surface. It consists of smoothly truncated spur ends, triangular facets. Geological observations along the Surprise Valley fault, at, or near, the base of the triangular facets, show that the dip of the facets generally is somewhere between one-third and one-half that of the fault plane.

The Surprise Valley front has been sculptured by numerous streams which in most instances run almost directly from mountain crest to mountain base. In the terminology of W. M. Davis these streams would be classed as consequent, with obsequent extensions, the extensions being the portions which now lie back, or west, of the original crest. At rather evenly spaced intervals these streams have cut cañons to such depth that commonly, slope wash, creep, and other processes of cañon widening have reduced intervening areas to knife-edged ridges. Between these major cañons and confined largely to the triangular facets are small gullies, "slits" in Davisian terminology. At the cañon mouths there are large alluvial fans. Below the gullies there are steep alluvial cones.

In longitudinal profile the major streams of the Surprise Valley front display three quite widely contrasted portions. At their headwaters, in the upper zone of oversteepening, their gradients are steep, their waters cascade downward over coarse rocky débris in narrow V channels which pay little heed to the differential resistance of the strata through which they pass. These turbulent streams soon encounter lesser gradients and slacken their pace in the second portion of the average longitudinal stream profile. Accompanying the lesser slopes of the typical portions of the upper element of ridge profiles we find rather broad and shallow stream valleys. In these, the turbulent tributary streams unite to form larger and more sluggish water bodies, which in some cases have aggraded their valleys to some extent and as a result have formed attractive mountain meadows. These meadows and valleys lie far above the range base so that below them stream gradients must again steepen to a very considerable degree. The lower zone of oversteepening generally starts some distance back of the break between the two elements of ridge profiles. In it the most picturesque scenery of the range is found. Falls of considerable height are common and gorges are often almost vertically

walled. These gorges remind one of those which enter the gorge of the Columbia River east of Crown Point. The most striking gorge of this type is found on Eagle Creek, a mile or so southwest of the town of Eagleville. So narrow is this defile that, during a flood in 1909, a pine log was lodged between its almost vertical walls 90 feet above the stream bed. In both the upper and lower zones of oversteepening considerable areas are so steep and rough that they can not be used for grazing purposes, in some instances even for sheep.

The western front of the range, in its northern half, is similar to the Surprise Valley front, but each element is represented to a lesser degree. North of Fandango Valley the western front is highest and the resemblance closest. At Fandango Valley an important embayment almost cuts the range in two, a break in continuity which has no counterpart on the eastern side of the range. South of this break the grandeur of the front is somewhat lessened, from tectonic causes, in that its rise is accomplished not in one great step but by means of a number of steps. Between the treads, stream channels are often diverted so as to temporarily parallel the front itself. Such streams often intercept the drainage from several large cañons above and consequently finally emerge at the range base as master streams, few in number but large in size. Another point of dissimilarity in the two fronts is that the alluvial fans of the western front quite often extend back deeply into the range.

The southern half of the western front differs widely from the range fronts thus far described. It is characterized by the absence of any escarpment and consists primarily of a long unbroken slope from range base to crest. The surface of this slope is for the most part concordant with the uppermost stratum of rock in the range and is one of the least dissected and most impressive dip slopes to be found in the Great Basin, extending as it does for distances of from ten to fifteen miles from the valley of the South Fork of the Pitt River to the loftiest crests of the Warner Range. Though several structural breaks occur at various places on this dip slope it affords numerous opportunities for walking entirely upon the surface of a single geologic formation from the base to the crest of the range.

From the foregoing discussion it seems evident that the northern part of the range is a horst and that the southern part is a simple tilted block. Adequate proof of this is furnished in subsequent portions of this report. The change from horst to tilted block is not abrupt. Toward the south the escarpment of the western front dies

out gradually, its termination finally taking place some distance south of Pine Creek South, southeast of Alturas.

The uplands of the horst portion of the range are comparatively smooth, basalt capped areas which have been but little altered by erosion. A number of cañons have extended themselves back into this territory from both range fronts but as yet they have not succeeded in reducing broad areas of original surface or in roughening it into features of erosional maturity. In the first ten miles south of Fandango Valley this simple upland condition has been somewhat altered by the pouring out of rhyolitic rock masses upon the original basalt surface. The rhyolites have cooled as volcanic domes which cause considerable surface irregularity. For reasons which are presented later it seems that these volcanoes are more ancient than the range itself.

Headwater basins⁸ are conspicuous in many parts of the range but particularly so in the central part of the western slopes, the best examples being the basins of Parker Creek, Pine Creek South, and Dry Creek, all of which are southeast of Alturas. None of these basins has yet advanced to the stage of isolating any former portions of the range from the remaining bulk of the mountainous mass. All of the basins are developing rapidly, however, under conditions which are extraordinarily favorable. On their sides sapping action goes on rapidly in walls composed for the most part of less resistant tuff and agglomerate capped by a thin sheet of basalt. In some cases almost vertical walls are formed, walls which frequently give rise to large landslides.

West of the Warner Range the front is paralleled by a long narrow trough. The northern part of this trough is known as Goose Lake Valley and contains a large, somewhat saline lake. South of Goose Lake Valley the trough is known as Pitt River Valley and is largely an old filled lake, covered on the east by encroaching fans from the range.

Beyond Goose Lake Valley and the northern part of Pitt River Valley there is a low plateau, of wide dimensions, known as the Gardens. For the most part the Gardens surface is a smooth lava cap but here and there small domes of rhyolite and obsidian rise above it. Still farther west, toward the western boundary of Modoc County, there has been not only comparatively recent rhyolitic

⁸ For discussion as to origin, etc., see Bryan, K., U. S. Geol. Surv., Water Supply Paper 449, p. 89, 1925.

volcanic activity but basaltic as well. Large areas are here covered by exceedingly rough masses of lava, cinder cones, and other forms of volcanic extrusions. This area is commonly known as the Modoc Lava Beds or as the Burnt Lava Country.

Surprise Valley, to the east of the Warner Range, is a trough of much grander proportions than the western trough. East of it rises the Hays Cañon Range with a front quite similar to but far less impressive than the Surprise Valley front of the Warner Range. From the summits of this range a broad plateau extends eastward, with minor interruptions, to the northern arm of the Black Rock, or Smoke Creek Desert.

STRATIGRAPHIC GEOLOGY

INTRODUCTION

In the geologic map seven cartographic units are used. In descending sequence they represent the following rock types:

Quaternary sediments

Obsidian

Rhyolite

Basalt

Andesitic tuffs, agglomerates, intercalated flows and sediments

Andesitic flows

Andesitic agglomerates, tuffs, conglomerates, intercalated flows and sediments

The selection of some of these cartographic units was clearly a matter of personal judgment. With his primary object that of the study of geologic structure, the writer selected units for mapping which best fitted that purpose. From a petrogenic standpoint the lower three units could well have been mapped together. In a rapid reconnaissance study they almost undoubtedly would have been. On the other hand if greater petrographic detail were sought they could be subdivided almost indefinitely. Similarly the obsidian and rhyolite might well have been grouped together in mapping from a petrogenic standpoint as they represent essentially the same geologic time subdivision and are practically of the same composition. The amount of detail shown brings out structural relations which might have been obscured by using fewer mapping units. Further subdivision would have required a great amount of rather non-productive field work, at least from a structural standpoint, and if carried to extreme would have introduced annoying cartographic complications.

ANDESITIC SERIES

CEDARVILLE SERIES

The lower three cartographic units used upon the geologic map constitute a series of andesitic rocks which makes up the great bulk of the mountain mass. This series resembles closely the Tertiary andesites of the Sierra Nevada but no means of positive correlation with these, or any other andesites, is known at the present time. So far as the writer is aware no name has been applied to the andesites of the Warner Range and contiguous territory. For the sake of convenience they will be called the Cedarville series. The three divisions of the Cedarville series will be called the Lower Cedarville, Middle Lava Layer, and Upper Cedarville.

LOWER CEDARVILLE

Distribution.—The Lower Cedarville is found only along the central portion of the Surprise Valley front for a distance of about thirty miles. Its greatest thickness occurs east of Buck Mountain and Squaw Peak, where an estimated minimum thickness of 3,700 feet exists with its base unexposed. From this area it thins out toward both the north and south, principally because of diminution in the height of the Surprise Valley front but also under the influence of transverse faults.

General characteristics.—The Lower Cedarville is essentially pyroclastic andesitic material, consisting for the most part of andesitic agglomerate and tuff. Intercalated between layers of pyroclastic andesite are flows of andesitic lava and, occasionally, small amounts of sedimentary rock. The relative abundance of each of these materials has been roughly estimated as follows: agglomerate, 50 per cent; tuff, 30 per cent; lava, 15 per cent; non-volcanic sediments, 5 per cent. From the base of the section to the top there are some changes in relative abundance which are quite striking. Agglomerate decreases and tuff increases in importance toward the top. The sedimentary rocks are confined almost entirely to the base of the section. Andesitic and basaltic dikes are numerous in the Lower Cedarville. At least one sill and two stocks of rhyolite were recognized as being intruded into the beds.

Basal member.—At the base of the exposed Lower Cedarville, particularly in the area between Cedar and Steamboat cañons, the lowest beds are fine andesitic agglomerates. Angular fragments of andesite, having diameters of three inches or less, are found embedded in a tuffaceous andesitic matrix. These beds are interesting from the standpoint of structural geology because a prominent set of joints has been developed in the fragments. The plane of jointing is similar to that of the Surprise Valley fault, a short distance farther east, in regard to strike and dip. The matrix seems to be free of such joint planes. No cases of displacement were found in the fragments. Convenient exposures of this material can be found within the first 200 yards of the range base along the road in Cedar Cañon.

Lignitic zone.—Toward the base of the Lower Cedarville, outcropping most conspicuously in the cañons between Cooks Cañon, about two miles north of Cedarville, and Milk Creek, about six miles south of town, there is a lignitic zone which has aroused considerable local interest and which has caused a great deal of prospecting and some attempted development, particularly in Cedar Cañon, about 400 yards west of the range base, and in Steamboat Cañon. At the base of the lignitic zone there is a considerable thickness of andesitic tuff, which grades upward into sandy and gritty materials, evidently indicating some reworking by stream action. More or less cross-bedding occurs in this material, but this disappears upward as the lignites are reached. The total thickness of the lignitic zone probably nowhere exceeds that exposed in Steamboat Cañon, where it is about 300 feet. The bulk of the material in this zone is a dark, fine, carbonaceous shale carrying seams of lignite, practically all less than an inch in thickness. The uniform thickness of the seams in outcrop might well have discouraged prospectors from expecting greater thicknesses back from the surface but it has taken twenty or more pits and drifts to definitely establish the fact that no commercial development will ever take place.

Coarse agglomerates and conglomerates.—Above the lignitic zone, for a distance of about 1,000 feet, coarse agglomerates prevail, although layers of tuff and sheets of lava are not uncommon. In the coarse agglomerates a considerable number of layers are characterized by well rounded fragments cemented firmly together by a tuffaceous matrix enriched by secondary calcite. These layers superficially resemble beds of fluvial conglomerate and, owing to the efficacy of their cementation, generally stand out in conspicuous outcrops.

Examination of the rounded fragments in all cases reveals a complete, or nearly complete, similarity in regard to rock type and suggests rapid accumulation. Lack of sorting is indicated by heterogeneity in the size of fragmental material in the conglomeratic layers. Petrified driftwood, always with well rounded angles, occurs rather abundantly. It seems likely that during the period of accumulation of the coarse agglomerates rather short pauses occurred which permitted stream action to round off the sharpest angles of the fragmental materials then upon the surface. That the streams were broad and had low gradients is suggested by the lateral extent of the conglomeratic layers and apparent absence of channels notched in underlying material.

Typical outcrops of Lower Cedarville coarse agglomerates and conglomerates are shown in figure 4, a view taken near the mouth of Cedar Cañon.

Upper members.—Above the coarse agglomerates and conglomerates the rest of the Lower Cedarville is composed chiefly of finer agglomerates and tuffs. Toward the top, alternations with flows of andesitic lava become rather numerous. Non-volcanic sedimentary rocks occur only very sparingly.

Stratigraphy.—In the whole of the Lower Cedarville there appears to be remarkable concordance, at least when it is considered that it is practically all volcanic. Individual layers are generally quite thin. Thicknesses of fifty feet represent the maximum for most of the intercalated lavas. Tuff and agglomerate layers sometimes double this figure but ordinarily they are from ten to fifty feet in thickness. In the lower horizons it is common to find layers of tuff less than a yard thick separating layers of agglomerate ten times their thickness or more. Toward the top of the section thin layers of agglomerate commonly separate thicker layers of tuff. Traced along the Surprise Valley front almost any layer will be found to pinch out but in a number of cases conspicuous layers can be followed twenty miles. There is a slight suggestion that more material was derived from sources east of the present outcrops than from the west in that a number of layers thicken slightly in being followed eastward. In any event the present outcrops are probably not far from the vents through which the andesitic materials reached the surface.

Fossil content.—Fossil wood is common throughout the Lower Cedarville. In the lower layers it is found as rounded driftwood in the conglomeratic layers. Stumps and logs either in place or nearly

so are common features in the tuff beds. At the top of the Lower Cedarville there is a very persistent "fossil wood zone" which can be used as a convenient key stratum. Most of the wood in this zone appears to be coniferous and not unlike our living Western Yellow Pine. Fragments are generally angular and are often opalized. Fossil leaf imprints occur at several stratigraphic horizons, the most

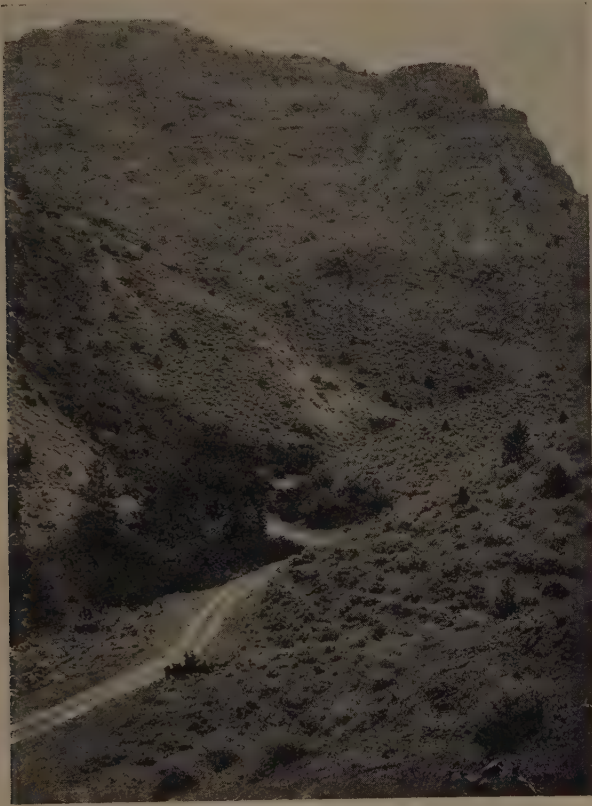


Fig. 4. Characteristic exposures of Lower Cedarville, near mouth of Cedar Cañon.

numerous localities occurring about midway in the section. Collections were made about two miles north of Cedarville and in Steamboat Cañon. Dr. R. W. Chaney has kindly furnished the following report on fossil plants collected from the Lower Cedarville:

A flora, found on the east slope of the Warner Mts. near Eagleville, appears to be a modified and somewhat younger phase of the Bridge Creek flora of eastern Oregon. Common Bridge Creek species occurring in it are *Sequoia langsdorfii*, *Alnus carpinoides*, *Platanus aspera*, *Rosa hillias*, *Ulmus brownellii*, *Umbellaria oregonensis*, and *Pteris silvicola*. In addition there are several species, as

yet undetermined, which are not found in the Bridge Creek flora, including an abundant *Cornus* or *Ehamnus*. In view of the well defined trend toward increasing aridity which is shown by the Tertiary floras of the northern Great Basin, the less humid facies of this flora from the Warner Mts. is an indication of its somewhat younger age than the Bridge Creek flora, which is referred to the Upper Oligocene. This places the age of the Warner Mts. flora as early Miocene or possibly latest Oligocene. From the fact that it does not contain the characteristic Middle Miocene floral element, the age of this flora cannot be supposed to be younger than Lower Miocene.

MIDDLE LAVA LAYER

Selection as cartographic unit.—The Middle Lava layer of the Cedarville series differs from other groups of sheets of intercalated andesite principally in regard to thickness and outcrop extent. Before selecting this particular group of flows for mapping purposes several other flows, or groups of flows, were investigated but being found less conspicuous or less extensive the project of mapping them was^a abandoned in favor of tracing out and mapping only the Middle Lava layer. This selection was also influenced by the facts that these flows are very near the center of the Cedarville and that the outcrop differences above and below it are rather pronounced.

Distribution.—The Middle Lava layer is exposed only along the Surprise Valley front, its limits being practically those already assigned the Lower Cedarville. The base of the layer is found at approximately the elevation of 6,000 feet in the cañon of Lake City Mill Creek where it forms conspicuous cliffs southwest of the Ranger station. Farther south the layer rises. In excellent cliff exposures just north of Cooks Cañon the base is found at an elevation of about 6,700 feet. It crosses the Alturas-Cedarville highway at an elevation of slightly less than 6,250 feet. Here it has been quarried extensively for use as road metal. In the highest part of the range it commonly attains the elevation of 7,000 feet on ridge crests but owing to its westward dip is found somewhat lower in the cañons. At Eagle Creek a cross-fault separates the layer so that north of the rupture it has an elevation of about 6,000 feet but to the south it is about 1,000 feet lower. Farther south, at Emerson Creek, another cross-fault marks the final disappearance of surface outcrops.

Lithology.—In the field, some of the hand specimens from the Middle Lava layer were provisionally called basalt. These were almost black in color, fine grained, almost glassy, with only small phenocrysts

of plagioclase visible. Subsequent microscopic examination brought out the fact that andesine and green hornblende occur as characteristic minerals in a fine groundmass of feldspar laths with little or no glass present. Generally, however, the lavas of this layer are grayish with large megascopic phenocrysts of green hornblende and plagioclase. In some cases the hornblende crystals are an inch or more in length. With quartz and olivine absent the reference of the Middle Lavas to andesite seems justified.

To work out the rock species in this layer, or in the rest of the Cedarville, would be a long but interesting task. The writer does not pretend to have made more than a very small start in this direction.

Stratigraphy.—The thickness of the Middle Lava layer, while quite uniform, is by no means constant. As a general rule greater thicknesses are found toward the south. This is the result of more numerous flows and also the thickening of individual flows in that direction. In the most northern outcrops the thickness of the layer seldom exceeds 150 feet, though lens-like swellings bring the value up to 250 and 300 feet in restricted areas. In the outcrops farthest south a thickness of 500 feet is common, but by no means constant. Individual flows rarely exceed 70 feet in thickness but this value is approximated at several places, for example in a cliff section near Cooks Cañon, in the exposures near the head of Cottonwood Cañon, and in the cliff section crossed by the profile surveyed across Cold Peak (fig. 2). It seems that the lower flow, or flows, in any given section is characteristically thicker than those above it. On this account the lower boundary of the layer was far more readily mapped than the upper limit, thin intercalated flows in the Upper Cedarville being readily mistaken for top flows of the Middle Lava layer.

UPPER CEDARVILLE

Distribution.—The Upper Cedarville is more extensive in its outcrop area than any other unit shown on the geologic map, covering about half of its total area. It is found along the Surprise Valley front above the Middle Lava layer, often extending upward to the range crest. On the western front it is the lowest rock exposed. Along stream courses, in headwater basins, and elsewhere where a capping layer of basalt has been removed, the resulting surface is sculptured

in Upper Cedarville. The outcrop areas of these beds are so well connected that one may walk continuously upon them from the southern to the northern end of the area mapped. In fact, the only disconnected areas of Upper Cedarville, represented on the map, are a few small patches in the southwestern part of the range along stream courses.

General characteristics.—The Upper Cedarville closely resembles the Lower Cedarville and is the upward continuation of the same general accumulation of andesitic rocks. It contains a greater proportion of tuff than the lower beds, the increase being at the expense of agglomerate. The relative abundance of various materials is roughly estimated as follows: agglomerate, 40 per cent; tuff, 40 per cent; lava, 15 per cent; and non-volcanic sediments, 5 per cent. These proportions change widely from place to place. In the area north of Bald Mountain agglomerate is relatively more abundant. In the vicinity of Cedar Pass tuff is more abundant and lava exceedingly rare. Toward the south the amount of lava increases regularly so that in the vicinity of Bear Mountain intercalated flows amount to 30 per cent of the whole. Intercalated sediments are almost absent in the southern area and agglomerate is more abundant than tuff. In ascending sequence changes in rock type are not as striking in the Upper as in the Lower Cedarville, excepting that in the southern area agglomerates are more abundant toward the base of the section and lavas toward the top.

Upper Cedarville agglomerates are characteristically finer in structure than those in the Lower Cedarville. Transitions from agglomerate to tuff take place so gradually in the upper beds that it is often impossible to draw exact boundaries between the two. For this reason large portions of Upper Cedarville appear to be massive in structure over wide outcrop areas. This is particularly true in the northern half of the range, especially between Cedar Pass and the north fork of Davis Creek. A section of this character is shown in figure 5. The outcrop appearance varies but little from the top to the base of the hillside. On close examination such outcrops contain many gradual transitions back and forth from fine tuff to fairly coarse agglomerate. The predominance of agglomerate in the outcrop is shown by the lapies-like⁹ weathering forms which are characteristic of that material rather than of tuff.

⁹ For a description of these features see J. Crijic, The evolution of lapies, Geog. Rev., vol. 14, no. 1, 1924.

Transitions from agglomerate to tuff, or vice versa, in some cases are sharply defined. This is particularly true at the base of agglomeratic layers and when more or less reworking or erosion of the underlying beds has taken place. The outcrop shown in figure 6 illustrates such a case. Here bedded tuff is overlain by rather fine agglomerate. The relationship between the two is that of erosional unconformity. Such unconformities are rather rare in the Cedarville series. They



Fig. 5. Characteristic exposures of Upper Cedarville, in the Davis Creek area.

are of limited extent and of little or no practical importance in connection with the geological history of the region. When sharp breaks occur between two differing types of rock material, however, the outcrop appearance locally resembles Lower Cedarville more closely than it does the major part of the upper beds.

Conglomeratic facies are exceedingly rare in the Upper Cedarville. Limited occurrences are found along the summits south of Payne Peak, just south of Cedar Pass, but their total outcrop area is probably less than five acres. The general absence of well cemented conglomerates, tending to stand out as prominent layers when the region is dissected, is one of the major points of contrast between the Upper and Lower Cedarville.

A striking point of contrast between the two chief members of the Cedarville is found in regard to the matter of secondary mineralization. Opalized layers of fine shale and tuff are common in the lower but not in the upper beds. Geodes, filled with chalcedony or calcite, and veins of calcite of such size and purity that they have been mined for optical use are Lower not Upper Cedarville features.

"*Chalk Rocks.*"—In the Upper Cedarville, near its top and occurring in at least three widely spaced localities, there is a peculiar



Fig. 6. Typical contact between tuff (below) and agglomerate (above) in Upper Cedarville, from Jess Valley.

phenomenon which seems to be associated with highly localized cementation of materials by calcite. This phenomenon is expressed in surface forms, conical structures, often ten or twenty feet in height appearing in white sandy tuff beds, generally where a considerable amount of pumiceous material is present. Figure 7 shows some of these cones occurring along the Alturas-Lakeview road about six miles northeast of Alturas, and which are known locally as the "*Chalk Rocks.*" Similar cones are found about seven miles southwest of Alturas, on the road to Salisbury Spring, and again, in large number, at Forty-nine Camp, east of Cedarville. In each case the materials in which the cones have developed are similar and the stratigraphic position, at the top of the series, is similar. The tuffaceous beds, out

of which the cones develop, can be traced continuously into the areas surrounding the cones, local details of sedimentation and jointing passing across without change. The cones seem to differ from the surrounding tuffs principally in that they carry numerous veins of calcite. These, then, seem to give us a clue as to the origin of the cones. Veins of calcite thus localized in outcrop area are suggestive of spring water deposition. The absence of present day springs at, or near, the cones does not necessarily argue against this hypothesis.



Fig. 7. "Chalk Rocks" about six miles northeast of Alturas.

The springs were probably short-lived anyway because no highly developed vents seem to have been formed, the calcite occurring along joint planes which trace out into beds on either side. Subsequent differential erosion seems to be responsible for the formation of the cones as they now appear. As the surface has been lowered the areas held by the presence of calcite veins have proved more resistant than adjoining areas not thus bound together. The development of conical, rather than more irregular forms, suggests that at present the cementation is more effective at the base than at the top of the strata of tuff involved. This might have been an original condition of deposition or might be the result of leaching more rapidly at the top at present. Generally the cones are found in valleys and with heights

approximating a common level. This suggests that the mineralization responsible for their development has taken place quite recently, when the valley bottoms were lowered down to the approximate level of the cone tops. This conclusion is directly in line with the notion that the jointing, which determined the course of the ascending waters which deposited the calcite, itself has been a late development. Furthermore they are located, in all cases, in the vicinity of faults which are known to be very recent and which are probably expressions of the same disturbances as the jointing observed in the tuffs.

Fossil content.—Very little fossil material has been found in the Upper Cedarville of the Warner Range. The small amount of fossil wood in the upper beds is in striking contrast with the abundance of this material in the Lower Cedarville. At many places in areas adjoining the Warner Range, Upper Cedarville fossils occur abundantly. Leaf impressions are readily found in the vicinity of Forty-nine Camp, east of the range, and along the Pitt River, particularly in the vicinity of the Pitt River Ranger station, about seven miles west of Canby. Both of these floras have been considered as Mascall (Upper or Middle Miocene) in age, by Chaney, who has furnished the following note:

A younger flora of the Surprise Valley region is found to the east, near 49-Camp, and on the Pitt River to the west. This flora is also found widely distributed over Washington, Oregon, and Idaho. Its age has been placed as Middle Miocene by Knowlton and by Chaney.¹⁰ The 49-Camp flora contains all of the typical Mascall (Middle Miocene) species, including the element composed of *Quercus pseudolyrata*, *Aesculus simulata*, *Juglans oregoniana*, and *Arbutus matthesii*. This element, which first appears in western America in the Miocene, indicates a considerable reduction in rainfall as compared with the preceding Bridge Creek conditions, which supported a typical redwood forest. It is not known to occur in rocks younger than the Miocene, for continued progression toward aridity appears to have cut down the rainfall to about 20 inches by the Pliocene period (in the northern Great Basin).

Vertebrate remains have been found in these beds at several places near Alturas, in Tuledad Cañon, south of the Warner Range, and in Warner Valley, to the north. While further paleontological work will be necessary before any positive assignment may be made on the basis of these, it is certain that they do not point to an earlier epoch than do the leaves.

¹⁰ Chaney, R. W., Distribution and climatic relation of the Mascall flora, Carnegie Inst. of Wash., Publ. 349, pp. 23-48, 1925.

DIKES

Dikes are exceedingly common in the Cedarville series. Judging from the numbers observed and the number of times they could be traced directly into flows it appears that the intercalated andesite and capping basalt flows of the range have had their origins mainly, if not entirely, in fissure eruptions. This seems consistent with the widespread distribution of many of the thin sheets of lava.

Because dikes are so numerous that their mapping would require a great length of time, and because of cartographic difficulties involved, none have been shown on the areal map.

Dike strike directions seemingly shed some light on problems connected with the orogeny of the range. They are discussed below in the Summary of Orogenic History.

Andesitic dikes.—In the Davis Creek area, particularly in the slopes east of Plum Valley, and as far south as Franklin Cañon, andesitic dikes are very numerous and very often can be traced into flows intercalated in the Upper Cedarville. Practically all of the dikes in this area strike about west and east and are vertical. Most of the dikes are narrow, two feet being a common width; although in some cases, as for example a conspicuous dike at the elevation of 6,250 feet on Roberts Creek, widths of fifteen or twenty feet occur. Ordinarily these dikes erode less rapidly than the materials through which they cut and therefore stand out as relief features, commonly rising a few feet above the surrounding surface. In some cases, however, dikes erode more rapidly, determine courses for the water involved in surface run-off, and are marked by long straight depressions. The most striking case of erosion on one of these less resistant dikes is found along the lower portion of Eagle Creek in the south-eastern part of the range. For a considerable distance this stream follows the Eagle Creek fault, as shown on the areal map. About a mile west of the boundary of the mapped area the stream abandons the fault line course and swings sharply east. This departure was caused by the presence of a huge andesitic dike on the east side of the fault which apparently offered better conditions for rapid erosion than the brecciated fault zone itself. Where the dike cuts through the Middle Lava layer a deep gorge with practically vertical walls has been eroded. In following through this gorge at present one finds the Middle Lava layer on either side but in the stream bed there

is the dike, only slightly narrower than the gorge several tens of feet vertically above.

Basaltic dikes wherever observed erode more slowly than the surrounding materials and therefore stand out as rocky walls. Horizontal columnar weathering often gives these dikes the appearance of long rows of piled cordwood. In this respect they differ markedly in appearance from the andesitic dikes, which are fairly smooth-surfaced. In many cases these rough basaltic dikes rise ten, twenty, or even a greater number of feet above the general surface. A good example of a basaltic dike is shown in figure 8.

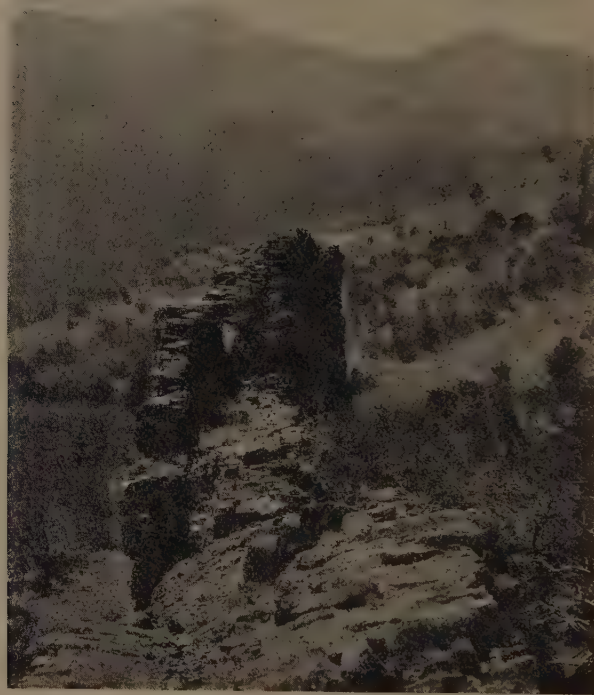


Fig. 8. Typical basaltic dike, on southeastern slope of Cold Peak.

For several miles north, from Cold Peak along the Surprise Valley front, basaltic dikes are exceedingly numerous, particularly near the range base. In a five-acre area about 500 feet above the range base in Highrock Cañon, west of Eagleville, between 10 and 15 per cent of the entire surface is composed of rather narrow basaltic dikes, giving the area the appearance of a woodyard.

On the slopes north of Dry Creek Basin, in the central part of the range, there is another interesting accumulation of basaltic dikes. A master dike, often 60 feet wide and 100 feet high, runs the entire length of the slope and connects with the sheet of basalt which caps the ridge between Dry Creek and Tom Creek. In a zone less than one-half mile east of this enormous structure there are 40 or 50 smaller dikes. Most of these parallel the large dike and vary in width from two or three to as much as ten or twelve feet. Near the floor of the Basin and near the eastern side of the dike area there is a hill, covering about an acre and about sixty or seventy feet high, toward which several dikes converge. The hill itself is made entirely of basalt resembling that of the dikes and has weathered out in typical cordwood fashion. The columns, produced by weathering, instead of being horizontal radiate outward from a north-south horizontal axis in the center of the hill near the ground. The whole structure is that of a large eddy. It seems probable that this basaltic accumulation was formed some 750 feet below the surface during the intrusion of the dikes and that it represents a space which, for some reason or other, became a collecting place for magma until a large knot formed. Possibly the eddy structure developed in connection with the last upward movements of the then relatively cool magmas. Now that erosion has lowered Dry Creek basin, some 750 feet below the capping sheet of basalt this queer knot-like mass has been brought to light.

Basaltic dikes are numerous in the Deep Creek area, west of Cedarville. Here they commonly strike north and south and depart as much from the vertical in their hade as the layers through which they cut depart from the horizontal in their dip. As the layers dip westward at about 16° the dikes dip eastward at 74° . This feature is observed elsewhere but in the Deep Creek area it is particularly evident because of the pronounced tendency of the dikes to strike with the Cedarville.

Contact metamorphism is often observed, in limited degree, on either side of the large dikes. The effects are most striking when the dikes pass through light colored tuffs, a pronounced reddening and baking being observable in some cases for several feet but ordinarily for only a few inches. East of Plum Valley such effects are common, associated with andesitic dikes. In the dike patch on Highrock Creek, Lower Cedarville tuffs are often conspicuously baked for distances of two or three feet. At the western end of the long ridge just south of Tom Creek, at an elevation of 6,500 feet, an andesitic dike about

two feet wide has proved itself less resistant to erosion than the tuff on either side of it and is now marked by a trough-like depression a foot or so deep. On the sides of the trough there are two little ridges, each a foot or so in height, each sloping steeply toward the dike depression but gently in the direction away from the dike, baked red and hard by contact metamorphism. From a deep brick red at the dike the color changes gradually to an unusually white tuff four or five feet away. This feature, though rather small, is one of the most striking evidences of baking and hardening found in the range.

WARNER BASALT

Distribution.—The most widespread rock surface in Modoc County is a relatively thin sheet of basaltic lava which probably covers about one-half the entire county. Northwest of Alturas, in the Gardens area, this sheet covers about 2,000 square miles and masks almost entirely the rocks beneath. It is covered by other rocks to only a very small extent. Southwest of Alturas this same sheet of basalt is the predominating surface rock but tectonic movements and erosion have exposed considerable areas of underlying rock to view. In the Warner Range the basalt covers about 30 per cent of the entire mountainous territory. Farther south, in the plateau area east of Madeline Plains, this sheet apparently covers most of the surface but its distribution has not been carefully studied. East of Surprise Valley and in the plateaus north of the Warner Range the basalt is very widespread in distribution. It is exposed in the great cliffs east of Abert Lake and in Warner Valley. Without much doubt this same layer can be traced at least as far as the westward slopes of Steins Mountain.

Name and correlation.—Because of the prominent exposures on the sides of Warner Valley and of the widespread distribution existing in the Warner Lakes Range and Warner Range it seems particularly fitting that the tremendous sheet of basalt in these and adjacent areas be called the Warner basalt. Of the various workers who have described portions of this sheet Merriam¹¹ alone seems to have used any names in connection with it, excepting that owing to mistaken correlation some have considered it to be the equivalent of the Columbia River basalts. In Virgin Valley, Merriam applied the name Mesa basalt to a portion of the sheet. East of this area, and to the north, it is very likely that this same sheet is, at least in part, his Pueblo

¹¹ Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, pp. 36–38, 1910.

Range series. In Thousand Creek it is very probable that the Railroad Ridge basalt is again a portion of the same layer. The definitions of any of these named parts of the widespread basaltic sheet are not sufficiently comprehensive to justify the adoption of any one of them for the sheet as a whole. In view of the somewhat uncertain nomenclature which has arisen in the Steins Mountain, Pueblo Range, Thousand Creek, and Virgin Valley area it would probably multiply confusion to try to apply any one of the names there used to the basalt farther west and south. For these reasons the basalt, so far as it will be referred to in this report, will be called the Warner Basalt.

Relationship to Columbia River basalts.—It has often been assumed that the extensive basalt sheets in northwestern Nevada, northeastern California, and southern Oregon represent the southern continuation of the Miocene lavas of Central Oregon. Blake, Waring, and others¹² have advanced this idea but in each case very little evidence has been used to back up the contention, for example, Waring¹³ boldly states that the basaltic flows “cover nearly all of Lake County and extend eastward beyond Steins Mountain and northward beyond the John Day region.” In the following paragraph he admits a lack of paleontologic evidence but states that “the material is so similar in lithologic character, in the amount of deformation it has undergone, and in its general relation to the Cascade Range to the west that there is little hesitation in placing it in the same general series with the widely extended and well-known Miocene lavas of Washington and northern-central Oregon.” In regard to “lithologic similarity” Waring seems ignorant of the fact that Miocene, Pliocene, Pleistocene, and Recent basalts of the Cascade and Great Basin regions are often practically identical. Instead of similarity in regard to his next criterion, “amount of deformation,” we find very considerable contrast existing. The Columbia River basalts, at least in most localities, have been subject to several periods of deformation. At Picture Gorge,¹⁴ if we select the best known example, there have been at least three periods of deformation, with long intervening periods of rest. From such a history it is a far cry to force a correlation with a basaltic sheet which has been subjected to but one period of deforma-

¹² See particularly, Blake, J., *Proc. Calif. Acad. Sci.*, vol. 5, pp. 210-14, 1875, and Waring, G. A., *U. S. Geol. Surv., Water Supply Paper* 231, p. 21, 1909.

¹³ Waring, G. A., *U. S. Geol. Surv., Water Supply Paper* 220, p. 21, 1908.

¹⁴ Figured and described by J. C. Merriam, *Univ. Calif. Publ. Bull. Dept. Geol.*, vol. 2, no. 9, 1901.

tion and that taking place very recently. The third class of evidence used by Waring, "general relation to the Cascade Range," suggests a belief that we should look in this direction for the source of the basalt. This is certainly not the case in the Warner basalt territory as numerous dikes connect with the sheet and are sufficient to explain its origin. The idea that the Columbia River basalts have similarly resulted from fissure eruptions is certainly not new or startling, in fact it is almost in universal acceptance. Is Waring resorting to an extraordinary type of negative evidence in this last cryptic statement or does "general relation" simply mean that both basalt sheets lie east of the axis of the Cascade Range?

Paleontological evidence, so far as it exists, argues against similarity in geologic age of the Warner and Columbia River lavas. The Columbia lavas are overlain by the Mascall formation. These beds contain a large vertebrate fauna and a well-known flora. The vertebrates indicate middle, or upper middle Miocene as the age of the formation.¹⁵ The flora has been considered to be in agreement with this determination.¹⁶ According to Merriam, the Mascall has a thickness of "not less than 800 to 1,000 feet" and six miles above Dayville it "dips as steeply as 30°." In the Warner Basalt territory, on the other hand, Chaney¹⁷ recognizes as Mascall, leaves collected beneath the basalt in the Upper Cedarville beds. While vertebrate evidence seems to contradict this age determination, it would place the Upper Cedarville even later in the geological time scale and thus render even more absurd the correlation of the two lava sheets. Thus paleontologic evidence pretty well establishes that the Mascall, distinctly above the Columbia River basalts, is to be sought for stratigraphically beneath the Warner basalt.

Thickness.—In the Gardens it is impossible to determine the thickness of the Warner basalt because very little erosion has taken place and the base of the sheet remains unexposed. Around the margins of this extensive plateau, however, it is often possible to measure the thickness in fault faces and in stream cañons. Near the southern end of Goose Lake the basalt is at least as thick as any exposed fault face bounding the Gardens. At the Old Fletcher ranch, at the southwestern corner of the lake, the basalts were studied in considerable detail and their exposed thickness measured with a transit. In a cliff

¹⁵ Merriam, *op. cit.*, pp. 304-7.

¹⁶ Chaney, R. W., *Carnegie Inst. Wash.*, Publ. 349, no. 2, 1925.

¹⁷ *Op. cit.*, p. 32.

section rising 439 feet above the June, 1922, water level of the lake the greatest single fault face measured 225 feet vertically and consisted wholly of basalt, with its base unexposed. Farther south, one-eighth of a mile north of the mouth of Tom Creek and about an equal distance south of the southern end of the gorge of the Pitt River below Joseph Creek, a section measured with an aneroid gave a thickness of 360 feet, with the base of the basalt unexposed. This thickness is considered a good minimum for the basalt in this region because it was taken a considerable distance back from any disturbing faults. Still farther south the basalt thins rapidly. This is noted both in the sections along the edge of the Gardens and also in the blocks which have been faulted down various amounts in the Pitt River Valley to the east. About four miles northeast of Alturas, in the only railroad cut made by the Nevada, California, and Oregon Railroad through basalt in this vicinity, at the 121 milepost of the railroad, the thickness of the basalt diminishes from 40 feet to 20 feet in a quarter of a mile. Above, in the rim rock of the Gardens, a similar thinning is observed. At the southeastern corner of the Gardens the basalt is but 15 or 20 feet thick. In a mile, toward the north, it grows to be over 100 feet in thickness. Along the rims of the south boundary of the Gardens the thickness of the basalt was measured quite accurately in a number of road cuts. In most cases thicknesses of 30 feet, or less, were found. In the area just north of the Essex ranch, about 10 miles west of Alturas, the basalt is repeated in a number of blocks, step faulting between the Gardens plateau and the level of Warm Springs Valley beneath. The thickness of the lava nowhere exceeded 40 feet in this area and is similar from block to block. Just south of Essex ranch is Rattlesnake Butte, an erosional remnant, also capped by a relatively thin layer of basalt but containing so much basaltic débris on its sides that it is often considered a small volcanic cone. Upper Cedarville beds, containing vertebrate remains, can be traced up the sides of the butte, beneath the talus mantle, almost to its summit.

In the area southwest of Alturas the basalt is characteristically thin and over a considerable part of the region is absent. The rim rock of this area is generally a conspicuous layer of agglomerate belonging to the Upper Cedarville and known locally as the "building stone." Though typically dark gray and highly pumiceous, at places the building stone is banded with pure white or bright red tuff, making it particularly conspicuous. In the areas where the building stone

has become the important rim rock, the Warner basalt was originally thin or entirely absent. Because of the absence of the basalt in those areas and because the building stone is such a persistent key stratum it is important to have it placed with reference to the basalt. A clear understanding of the stratigraphy is also necessary for the interpretation of the paleontology of the area because the leaf imprint localities are all above the building stone while all of the vertebrate localities are at least one hundred feet below it.

In the slopes leading up to the Gardens, particularly in the vicinity of the several branches of Rattlesnake Creek, the building stone outcrops conspicuously as a second rim a short distance below the main rims of Warner basalt. In the area southwest of Alturas, at the western summit of the road leading to Cañon Creek, Scott ranch, Ivory ranch, Salisbury Spring, etc., 6.9 miles southwest of town, the following section was measured:

	Feet
Top—Warner basalt	15
Upper flow, fresh, black, olivine basalt	10
Lower flow, reddish weathering, vesicular basalt	5
Yellow pumiceous tuff without coarse fragmental materials	10
Yellow agglomerate with numerous layers of sandy or gritty white tuff, often pumiceous	50
Buff pumiceous tuff with minor amounts of cross-bedded white sandy tuff	30
Building stone. Dark pumiceous agglomerate weathering into a black sand, cliffy in outcrop, with numerous caves	60

This section is valuable not only because it represents one of the few in the area southwest of Alturas where the relationship between the basalt and building stone is absolutely certain, but also because the most productive vertebrate beds are in close proximity to it.

In the Warner Range east of the Gardens the thinning of basalt from north to south is very similar to that already described for the Garden margins. Just south of Fandango Valley thicknesses of 500 feet are not uncommon. On the eastern side of Sugar Hill and along the western side of Lassen Creek this thickness is exceeded with the base of the sheet unexposed. Farther east, toward the range crest, the basalt is thinner but not because of original variations in thickness. Here lower and not upper flows are exposed at the surface and in places the whole sheet has been removed by erosion. Still farther east, across Surprise Valley, the basalt has not been lifted high into the zone of erosion and thicknesses are again as great as those near

Sugar Hill. The thick basalt of this area thins to about 100 feet in the Davis Creek area, and farther south toward Tom Creek, sections measuring over 50 feet are rare.

South of the south fork of Parker Creek the long westward dipping slopes are covered by basalt almost continuously to the end of the range. Pine Creek basin, the gorge cut by East Creek, and the area east and northeast of Jess Valley are the main areas where underlying rock has been exposed as a result of erosion. At several other places normal faulting has broken the continuity of the sheet. Observations in these and other areas indicate that, within certain limits, the basalt varies in thickness quite considerably in this southern half of the range.

East of Likely, on the rims just north of the south fork of the Pitt River, for about three miles the basalt is less than 30 feet thick. Where the Pitt first enters a distinct cañon the thickness is 50 or 60 feet. At the first road crossing east of Likely, on the Jess Valley road, near the beginning of the gorge, a section was measured in which 78 feet of basalt overlies 165 feet of Upper Cedarville tuffs and agglomerates. Three miles east of this section, one-half mile west of the only cold spring in the deep gorge, another measured section consisted of 350 feet of basalt overlying about 250 feet of tuff and agglomerate. About a mile northwest of this latter section and very near the west end of the surveyed profile across Cold Peak the basalt is 300 feet thick. Farther east, toward Jess Valley, it is thinner. This is partially due to erosional removal in the fault zone area just west of the valley but it cannot be entirely explained on that basis because top flows are present in many of the exposures. Original thinning down to as little as 125 feet seems to have taken place in the Jess Valley area. East of the valley, toward the range crest, variations in thickness commonly occur between the limits of 150 and 300 feet, these variations being caused, for the most part at least, not by erosion but apparently indicating original thickness.

In the southern area, particularly along the range crest wherever erosion has not interfered, the thickest basalt sections are found in the area of Eagle and Cold Peaks, where it is not uncommon to measure sections as thick as 600 feet. North of this there is gradual thinning to 150 feet, and less, in the Buck Mountain region. A similar regularity exists in regard to thinning toward the south. In the northern part of Lassen County the sheet seldom attains a thickness of over 200 feet.

In summarizing the variations in thickness of the Warner basalt one must be impressed with constancy rather than variability. Where the base of the basalt is exposed, in a thousand square miles more or less, the limits of variation lie between 600 feet and 0. It seems remarkable that the flows left little territory uncovered and yet failed to pile up locally to greater thicknesses. That they must have spread over rather even surfaces is well shown in the area just west of the range. The persistence of thin rims east of Pitt River Valley and along the southern margin of the Gardens certainly indicates as little local relief at the time of the outpouring of the lavas as exists there today. That the area immediately southwest of Alturas escaped covering, at least for the most part, possibly indicates that elevations there were slightly greater, slightly above the upper surface of the last basaltic flows. The three areas of greatest thickness, (1) the east-west strip from the Gardens to Nevada in the latitude of Sugar Hill, Lassen Creek, etc., (2) the irregular (north-south?) area west of Jess Valley, and (3) the irregular, mostly north-south, thickening in the Eagle Peak, Cold Peak area, might suggest depressions in the Upper Cedarville surface at the time of the basalt outpourings, or depressions formed during that period. Clearly such depressions could not have been of erosional origin because a remarkable degree of concordance exists between the Cedarville and the Warner basalt. Locally there are small erosional unconformities but these have no greater importance than similar breaks in the Cedarville itself. Orogenic depressions would be reflected in the attitude and structure of the Upper Cedarville. They are apparently absent. The variations in thickness seem to take place wholly in the basalt itself. Where the sheet is thin it has a remarkably even surface. Where it is thick the present surface is more irregular. The thickened areas are probably the areas where most of the basalt came to the surface. Distinct cones or domes are not suggested by any of the surface irregularities that exist at present. In two of the three areas of greatest thickness, underlying dikes are for the most part obscured. This is not the case in the Eagle Peak-Cold Peak area, however. The great number of basaltic dikes exposed on the Surprise Valley front has already been described in connection with the Cedarville series. In that area the thickening strikingly suggests relationship to these numerous and very conspicuous dikes. It should be noted, however, that thickening does not always occur where dikes are numerous. The remarkable dikes of the Dry Creek area, some clearly traceable into the basalt

sheet, are in an area where erosional remnants indicate that originally the thickness of the basalt was not great. Possibly the Dry Creek area stood at slightly higher elevation than the surrounding territory. This would account for the thin sheet of basalt covering it and also for the fact that this thin sheet consists of upper flow material exclusively.

Lithology.—All of the Warner basalts seem to contain labradorite feldspars in their more or less glassy groundmass, labradorite or anorthite phenocrysts, augite, and olivine as essential constituents. Commonly the period of crystallization of the augite seems to have been about as late as that of the feldspar phenocrysts as intergrowths of the two are very common. Generally there is a considerable amount of magnetite present but this varies considerably from place to place. In some localities the magnetic compass is worthless.

Variations between individual flows of basalt are generally quite superficial in nature. The upper flows are characterized by more open structures than are the lower flows. Upper flows are often porous to the extent of being sponge-like, each vesicle typically being small and calcite-filled. In lower flows vesicular structure is less common and when it does occur the individual vesicles are likely to be larger and farther apart. A more striking and more fundamental difference between the flows is that in ascending section there is a rather pronounced change from more crystalline to more glassy types of basalt. With this change comes a general reduction in size of the feldspar phenocrysts, those in the spongy, glassy, upper flows just barely being megascopic. From these differences one is able to judge roughly the place of any particular flow in the basaltic sequence.

The homogeneity observed in the Warner basalts and the superficial nature of differences observed in vertical section is suggestive of a short period of accumulation.

In the upper flows there are certain features which appear to be horizontal eddies as evidenced by peculiar flow structures. One of these is shown in figure 9, a block that has been transported some distance and deposited on the floor of Jess Valley. In this block, flow structures which run from left to right across the lower portion turn up at the right of the block and in the upper portion continue back from right to left. This is not a particularly good example of horizontal eddy structure but was one of the few which could be readily photographed. Usually the eddies are found on cliffs, where they

weather out as conspicuous features probably because the basalt in them is relatively dense and free from vesicular structures.

The most striking horizontal eddy is to be seen at the elevation of 6,100 feet on the north side of the north fork of Davis Creek about a mile east of the place where the road leaves the creek and turns north, up a slight pitch, to the alluvial area shown on the areal map. The diameter of this eddy is about twenty feet. Its axis is horizontal and oriented about north and south. The individual layers of flow



Fig. 9. Eddy structure in Warner basalt, from Jess Valley.

structure in this eddy bend around on themselves completely and suggest that some forward motion occurred while the lava was cooling. If such eddies result from semi-molten material overriding more solidified, cooler material which preceded it in flowing away from the volcanic vent, the flow direction here indicated is from west to east because the flow structures at the top of the eddy apparently continue into the horizontal flows west of the eddy.

Other eddies are rather numerous in the vicinity of Benton Meadow, particularly along its western edge. In all cases their axes approximate the plane of bedding of the surrounding lava but the orientation of axes is somewhat variable around a general strike direction of northeast. The basalts just east of Jess Valley contain similar eddies.

Comparison with Recent basalts (Modoc basalt).—The Warner basalts present a surface characterized by topography quite unlike that of the recent Modoc basalts of the Modoc Lava Beds. This is recognized by the people living in the area who restrict the term "Gardens" to the plateau of Warner basalt west of Goose Lake but who use the terms "Lava Beds," "Burned Lava Country," or "Lava Fields" for the continuation of the same plateau surface covered by the more recent effusives. The surface of the Gardens is relatively smooth and subdued. The Lava Bed surface is exceedingly irregular, large portions of it being so rough that they cannot be crossed on horseback. Caves are frequent in the Lava Beds but absent from the Gardens and other areas of Warner basalt. The Lava Bed caves radiate out from Glass Mountain like spokes from the hub of a wheel. Some of the individual caves have been explored and mapped for distances as great as 16,000 feet. These caves were the stronghold of the Indians at the time of the Modoc War. At places the roofs have collapsed leaving holes commonly known as "wells" or "pipes." Between such openings ice caves are not infrequent. Several "natural bridges" remain standing across long caves with almost completely collapsed roofs. The surface irregularity of the Modoc basalt is so great that we are forced to the idea of very recent origin, not as recent as the lavas of Craters of the Moon National Monument, in south central Idaho, but certainly within the last few centuries.

RYOLITE

Distribution.—Flows of rhyolite overlie the Warner basalt on the summits between Fandango Valley and the south fork of Davis Creek. In the southern part of the range a small patch of rhyolite caps Cold Peak. Stocks of rhyolite intrude lower Cedarville beds on the north side of the cañon of Lake City Mill Creek, about one-half mile west of town, and again just north of Goose Creek in a quarry at the range base near the stone schoolhouse. On the west side of the range, along the road connecting the Alturas-Lakeview highway with the Alturas-Cedarville highway, near the range base north of Tom Creek, rhyolite stocks occur in upper Cedarville beds. At the junction of Tom Creek and the Pitt River several stocks of rhyolite intrude Warner basalt. A small sill of rhyolite occurs in the lower Cedarville at the mouth of Steamboat Cañon.

Outside of the territory studied intensively Warner basalt is very often overlain by rhyolite. In the Gardens, hills of acidic lava rise as gentle domes above the flat basalt plateau. At Mount Bidwell, at the northern end of Surprise Valley, 250 feet of rhyolite caps the basalt. East of this peak this relationship is repeated at least four times in a beautiful series of step faults. Farther north, above Eight Mile Creek, extensive sheets of rhyolite cover the basalt. A particularly good section was observed near the road summit between Twelve and Twenty-Mile Creeks, south of Adel. In the Hays Cañon Range, east of Eagleville, rhyolite again outcrops extensively on the summits, overlying the basalt.

The large mass of rhyolite south of Fandango Valley is now separated into several distinct outcrop areas but formerly these were all connected. The two isolated outcrop areas just east of Sugar Hill have been separated as a result of downcutting of Lassen Creek. Another separation from the larger mass is the result of rather recent faulting. This whole mass rests upon a smooth and even surface of basalt, the relationship being that of concordance. At Sugar Hill the rhyolite is over 1,000 feet thick. From this maximum it thins out rapidly in all directions, the terminations of the mass being so abrupt that they are usually expressed topographically. The greatest extension of the mass is toward the southeast, it being about nine miles from the boundary of the rhyolite to Sugar Hill.

The geographical distribution of rhyolite in the Gardens indicates a close relationship with the Warner Range. The easternmost rhyolitic hills of that plateau are just across Goose Lake from the large mass of rhyolite in the range. From east to west these later acidic rocks seem to be distributed along a fairly well defined belt. At the western side of the Gardens this belt widens, rhyolite becomes more widespread in distribution occupying a place in the stratigraphic sequence between the Warner basalt and the recent Modoc lavas. The rhyolitic domes on the eastern side of the Gardens compare favorably in size and thickness with the Sugar Hill-Davis Creek body. They rise above the same flat floor of basalt. In all probability they give us a good picture of the appearance of the Sugar Hill-Davis Creek body as it originally existed.

The east-west zone of rhyolitic rocks either terminates at the Warner Range or bends there and continues toward the north. In the floor of Fandango Valley the rhyolite is absent but it occurs again in the summit areas north of the valley and from these summits seems

to outcrop more or less continuously toward the northeast, across Mount Bidwell and toward Warner Valley.

The small patch of rhyolite at the summit of Cold Peak suggests a former connection with the flows at the summit of the Hays Cañon Range. The Cold Peak rhyolite is isolated from any other acidic rocks in the Warner Range. No rhyolitic stocks, dikes, or other indications of origin exist in its vicinity. Immediately across Surprise Valley, at the head of Hays Cañon, a sheet of rhyolite, seemingly quite widely developed on the plateaus to the east, extends as far as the range crest. Farther north, along the Hays Cañon Range summits, the uppermost rock is basalt, just as it is in corresponding positions west of Surprise Valley, on the Warner Range summits.

Relationship to Warner basalt.—It has generally been thought that the rhyolites of northwestern Nevada and south-central Oregon are older, at least for the most part, than the extensive basalt flows which cover so much of that territory. Careful examination of literature will reveal much meager and unsatisfactory evidence in support of this general conclusion and field observation will, in a great number of cases, disprove it.

Waring's¹⁸ geological map of the region just north of the Warner Range shows hills of acidic rock rising above flats of basalt just as if the acidic accumulations were younger than their basaltic floors, and nowhere does he show basalt resting upon rhyolite. His interpretation of the stratigraphic succession is that the basalt is young, having flowed around the rhyolitic hills. Practically no evidence is offered in support of this conclusion. In view of the fact that large masses of rhyolite overlie the basalt in the area just to the south, it was felt that an examination of a portion of the area mapped by Waring would be desirable. The Coyote Hills, about ten miles northwest of Plush, were selected for this purpose because of their being the closest of Waring's mapped rhyolitic areas to the Warner Range.

The Coyote Hills are the eroded remnants of a dome-like uplift of the Warner basalt, in the center of which a rhyolitic core is exposed. The hills are about five miles in diameter, the core about two and a half. In traveling toward the center of the hills one ascends dip slopes of basalt, reaches minor summits at the present ends of the several flows involved, and descends short, abrupt slopes, facing the central core, each descent bringing him to the dip slope of the next basalt layer beneath. The basalt might be described as forming a number

¹⁸ Waring, G. A., U. S. Geol. Surv., Water Supply Paper 220, 1908.

of *cuestas*, concentric in arrangement and with the curving escarpment of each facing the central mass of rhyolite. The highest summits seem to be composed of basalt, the lowest flows, stratigraphically, those of the innermost *cuesta*. Beneath the lowest basalt exposed are andesitic tuffs and agglomerates, apparently the Upper Cedarville. If the base of the lowest basalt flow were extended, as a broad dome, it would pass well above the top of the highest points of rhyolite. Though the area was not mapped and no transit observations were made it seems perfectly safe to predict that Upper Cedarville beds, a hundred feet or more beneath the basalt, would similarly pass above the rhyolite if we were to reconstruct the hills minus all effects of erosion. The rhyolitic core is composed of fragmental and brecciated rhyolite; flows seem to have been absent. The absence of flow structures is a point of great contrast between these rhyolites and others spread out above the basalt in the region to the south and southeast.

In the interpretation of the geology of the Coyote Hills it appears that the rhyolite is younger than the basalt. If we accept Waring's idea that the basalt flows surrounded an island of rhyolite we are still left in the dark as to the reason for the existence of the present hills because the highest summits are made of basalt and the rhyolite forms a basin within. If we seek the explanation of the origin of the hills it is clear that we must deal with the forces which produced a doming of the area. In the writer's mind the rhyolitic core explains the doming. He pictures the area now the Coyote Hills as having at one time been flat, as is the surrounding territory for tens of miles, capped by Warner basalt, and underlain by Upper Cedarville beds. Subsequently, in the general period of later rhyolitic activity, he pictures rhyolitic magmas approaching the surface but being unsuccessful in reaching it, collecting, *laccolith*-like, some distance below and causing the overlying basalts to be raised, blister-like, into a gentle dome. Fissures and cracks formed by tension, in the upper portions of the basalt surface, hastened erosion so that at present much of the summit area of the old dome has been removed and the upper portions of the rhyolitic core have become exposed. Unless an erosional contact is found between the rhyolite and the basalt or andesites, with the latter materials clearly resting on the former, it seems impossible to agree to Waring's interpretation.

In the region south of Harney Valley, Waring¹⁹ notes frequent occurrences of rhyolite above the "Main Lava Flows," but owing to

¹⁹ Waring, G. A., U. S. Geol. Surv., Water Supply Paper 231, 1909.

a very generalized and unfortunate choice of cartographic units these are not shown on his geologic map. South of the Harney Valley region Merriam²⁰ also reported basalt capped by rhyolite. It is probable that the full significance of faulting is not appreciated and that several misinterpretations of the geologic history appear in this paper. Rhyolite masses, often of considerable thickness, overlie the basalt sheet which forms the broad plateaus west of Virgin Valley. Farther east they have been dropped or tilted by the movements of relatively recent block faulting. These detached masses of rhyolite, in the Virgin Valley and Thousand Creek paper, were regarded as belonging to some earlier period of accumulation. The writer, in investigating this area, in the summer of 1926, noted that some of the rhyolites just west of Virgin Valley are exceedingly recent in origin, not only covering flat basaltic areas but also flowing down cañons recently eroded in the sides of the mesas. It thus appears that the rhyolitic period began before the last general period of faulting and, like the period of faulting, has continued practically to the present.

In the Warner Range the relationship between rhyolite and Warner basalt is perfectly evident. The mountain uplift and subsequent cutting by streams have exposed the contact with absolute clarity. Forest growth and talus accumulations obscure portions of this interesting line but in intervening areas it is so clear that it may be projected across the covered areas with little or no hesitation.

The base of the small rhyolitic outcrop at the summit of Cold Peak is readily followed and indicates concordance of the acidic rocks with the basalt just beneath.

In the northern rhyolitic area of the Warner Range the base of the rhyolites often occurs on cliff faces. These are found at the crest of the Surprise Valley front, the western front, and above cañons. The cliffs have been formed by the sapping action taking place in the Upper Cedarville with the result that the basalt and rhyolite have become a cliffy rim rock. It is in such faces that the contact is observed with greatest accuracy.

Where forest growth and relatively deep soil obscure the contact its position may be approximated, in many cases, by spring locations. There are more fissures and cracks in the rhyolite than in the basalt. The basalt, being less pervious, checks downward seepage to a con-

²⁰ Merriam, J. C., Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada, Part 1.—Geologic history, Univ. Calif. Publ. Dept. Geol., vol. 6, no. 2, 1910.

siderable degree, with the result of numerous contact springs. These occur frequently on the sides of Sugar Hill, and west of Lassen Creek, above the old Harris place, they have been utilized as water supply for a lumber mill south of Sugar Hill.

Where the contact is obscured by talus, notably on the west side of Sugar Hill, the highest basalt fragments give some indication of the contact but this is the least satisfactory criterion of all owing to the large size and predominance of rhyolitic blocks.

The whole rhyolite-basalt contact indicates a remarkable degree of concordance between the two lavas.

Very little residual soil seems to have been formed on the basalt prior to the deposition of the rhyolite, at least practically none is to be seen at present. This is not surprising in view of the fact that little or no soil is to be found on the basalt flats of the Gardens at present. Either removal by wind is rapid enough to prevent the formation of residual soil or else the time elapsed since the pouring out of the Warner basalts has not been long enough under obtaining climatic conditions. Removal by wind seemingly has not played a very important rôle because the basalt surface is practically always composed of the upper flows of Warner basalt, beneath the rhyolites as well as over the uncapped areas. The disintegration of horizontal basalt sheets is seemingly a very slow process. The general absence of large phenocrysts in the upper flows, together with the vesicular structure of the rock, probably has much to do with this. Changes in temperature reduce some of the rocks at the immediate surface but the layer of *débris* so produced acts as a protective blanket to the rock beneath. On flat surfaces this relatively thin blanket seems to be removed with almost incredible slowness. Frost action is relatively unimportant because the surface of the basalt is normally dry, water seeping downward very rapidly after periods of precipitation. The region, though humid, supports a steppe flora at present because of the rapidity with which it drains. Thus a layer of rhyolite poured out at the present time so as to cover a portion of the flat-lying Warner basalts would not be separated from the basalt by any great thickness of soil accumulation. It is of little wonder, then, that if the time elapsed since the end of the basaltic period has not been sufficient for the formation of residual soil, the smaller period between the basaltic period and the rhyolitic period was similarly incapable.

Relation to period of faulting.—That the rhyolitic period antedated the period of faulting is, in some cases, indicated by the fact

that faults cut rhyolite. As faulting has continued down to the present, however, this might only mean that the rhyolites antedate the last ruptures. In the case of the flow on the summit of Mount Bidwell and the four repetitions of the rhyolite-basalt contact beneath, it is certain that the rhyolite antedated the initiation of faulting because it is of similar thickness on each of the fault blocks and is present as the cap of the graben floor to the east, north of Lake Annie. The suggestion that the Cold Peak flows are the continuation of the rhyolites just east, at the summit of the Hays Cañon Range, seems most rational from a consideration of the present distribution of those rock bodies. If such be the case the connecting rhyolite is now deeply concealed in Surprise Valley and the rhyolites antedated the formation of the graben.

That the rhyolitic period did not wholly antedate the faulting is indicated by the connection between rhyolitic stocks and recent fault lines. The Lake City rhyolitic stock is on the main Surprise Valley fault. The stocks near the mouth of Tom Creek are definitely aligned along the fault which marks the eastern boundary of the Gardens. The rhyolites in the vicinity of Virgin Valley are even more instructive, for while some of them antedate faulting others postdate much of the subsequent erosion.

The period of rhyolitic effusion, while in the main giving rise to rock masses which antedated the main faults of the Warner Range area, has apparently continued down to within very recent times. Whether rhyolites have been extruded since the Modoc lava flows took place is an open question. In the Lava Beds area itself it seems improbable that any of the lavas are more recent than the Modoc flows. South of the main Lava Beds the basalts distinctly rest upon rhyolites.

OBSIDIAN

Distribution.—Seven small outcrops of obsidian occur in the rhyolitic area between Sugar Hill and Davis Creek. Fragments of obsidian are exceedingly numerous in the stream cañons below. Scattering fragments found as far south as Bald Mountain indicate that drainage conditions in the past made it possible for obsidian float to be carried that far south, a thing which is impossible today. South of Bald Mountain obsidian fragments are rare or absent, as far as the general vicinity of Patterson Mill, near the headwaters of East Creek. The distribution of fragments in the Hays Cañon range is

similar to that in the Warner Range, the territory south of Hays Cañon being generously covered while toward the north the material becomes less common, or is absent. That the material on the two sides of Surprise Valley was derived from the same outcrop is a distinct possibility but the discovery of the outcrop was not made; possibly it lies deeply buried beneath Quaternary sediments in the valley. Fragments of obsidian are common in the Gardens. Timbered Mountain about twelve miles west of the southern end of Goose Lake is, at least in part, composed of this material. For a mile or so the road between Crowder Flat and Alturas is literally paved with obsidian float as it passes Timbered Mountain. Farther west, Glass Mountain, and in Siskiyou County, Little Glass Mountain, are in the main accumulations of obsidian.

Relationship to rhyolite.—The isolated obsidian outcrops everywhere overlie rhyolite. Each outcrop seems to represent an individual vent although it is possible that the present distribution is misleading and that there was but one obsidian flow covering a portion of a very irregular rhyolite surface. On the summit of Sugar Hill the base of the obsidian is well over 1,000 feet above the base of the rhyolite while two miles southeast it is less than 200 feet above the same datum. Three and one-half miles southeast of Sugar Hill the obsidian is within 100 feet of the base of the rhyolite but three miles still farther the rhyolite is 500 feet thick beneath obsidian.

For nearly one-half mile along the summit just north of the headwaters of Boyd Creek, the contact between the rhyolite and obsidian is clearly exposed. As shown in figure 10, this line is fairly uniform and appears to be the base of a thin flow. Beneath the obsidian the rhyolite rises as a conspicuous gray cliff to a maximum height of about 150 feet. Above the contact there are no rhyolitic fragments, the surface being entirely covered by obsidian spalls up to ten inches in diameter. These spalls lie at an angle of repose of about 30° . As the rhyolitic cliff recedes the obsidian spalls fall over the cliff but new spalls are furnished by the weathering of the parent rock beneath so that no solid obsidian is ever exposed.

Hilltop outcrops.—The association of obsidian outcrops and hilltops is very striking, there being no cases where the glass is found in place in any other position. This seems to be due to the protection afforded an area by an obsidian capping, in effectively resisting erosion.

Wherever very recent obsidian rocks are found one is impressed by the rapidity with which mechanical disintegration occurs. At the base of any obsidian cliff the growing talus pile is largely composed of blocks often having diameters of several feet. Active disintegration of this type can readily be observed at Obsidian Cliff, in Yellowstone Park, or at Little Glass Mountain, in California. The outlines of blocks detached from the parent mass are joints developed largely as the result of alternating expansions and contractions produced by daily temperature changes. Indeed disintegration goes on so rapidly

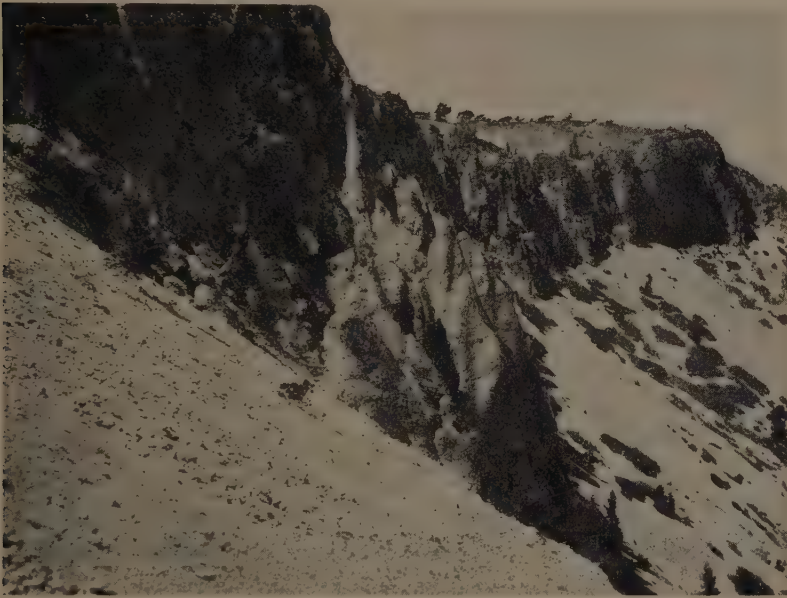


Fig. 10. Obsidian capping rhyolitic cliff, near headwaters of Boyd Creek.

that one actually hears it taking place, particularly in the mornings as the rocks expand under the warmth of the sun.

After detachment obsidian blocks disintegrate further into smaller spalls, partially the result of impact if the blocks have moved some distance downward to or on a talus slope but also as a result of the same processes responsible for the detachment of the blocks originally. These spalls are very irregular in shape, their faces being conchoidal fractures. Partially as a result of this irregularity of shape, and also because of the absence of effective transporting agencies, such spalls tend to accumulate at relatively high angles of repose. Under conditions obtaining in northeastern California, spalls having average diameters of two inches or over, commonly form talus slopes standing

at apparent equilibrium at slope angles of 30° or greater. Spalls an inch or so in diameter often maintain angles of more than 20° . Such slopes mean a comparatively rapid covering of the parent outcrop. In the Warner Range all original outcrops have long since been so obscured.

After an obsidian outcrop has been covered by the *débris* of material detached from it, the *débris* continues to break up into smaller and smaller fragments as long as processes capable of producing this end are in operation. There seems to be a limit to such disintegration, however. In northeastern California this limit is reached when the fragments in the *débris* reach about an inch in diameter. In obsidian talus and in the *débris* covering the hill summit outcrops fragments less than an inch in diameter are comparatively rare. Very commonly, however, particularly on the summits, an extensive area may be covered by fragments of almost uniform size just exceeding an inch in diameter. This seems a probable indication that expansion and contraction produced by changes in temperature such as are characteristic in northeastern California will not reduce the fragments below the limiting size. Further evidence in this direction is afforded by the westernmost obsidian outcrop just north of the north fork of Davis Creek. Here a considerable forest growth is found above the obsidian. The protection afforded by the forest undoubtedly lessens the daily range of temperature at the ground surface beneath and hence retards mechanical disintegration. The obsidian fragments of this outcrop are quite uniform in size but the average diameter is close to two inches, whereas on unprotected outcrops a short distance east it is the customary inch.

A limiting size of obsidian fragments means that, other conditions being equal, there is an effective limiting angle of repose of obsidian talus. Observation indicates that, in the absence of an effective outside means of transportation, this angle is relatively steep, being some 20° , or more. In the case of the outcrop near the headwaters of Boyd Creek (fig. 10) an effective transporting agent exists due to recession of the rhyolite cliff beneath. Here the obsidian slope retreats, parallel to itself, as the floor beneath it is withdrawn. In most cases, however, such conditions are absent, the angle of repose of the obsidian slopes is steeper than the territory beneath and hence the talus is quasi-permanent as a blanket above the parent rock.

An obsidian talus blanket is an effective check on further disintegration of the parent rock. The blanket is composed of loose blocks

and fragments of irregular shapes. Air between the blocks and fragments affords effective insulation and the changes in temperature taking place at the immediate surface soon disappear at depth in the talus. Precipitation seeps downward with great rapidity in the talus. In the absence of surface run-off practically no gullies are formed and very little slope wash takes place. As very little material is dissolved, or affected chemically, by this rapid seepage of relatively pure water it is probably a negligible factor in the weathering of the rock beneath.

The rhyolite immediately beneath all obsidian outcrops in the Warner Range weathers much as does the obsidian but with the important difference that, owing to the characteristic fine banding of the flow structures, it forms flakes rather than irregular blocks or fragments. These flakes are reduced to almost paper thinness in final stages of disintegration and are consequently easily broken down into sandy materials which work down to rather low angles of repose on slopes. The presence of phenocrysts also assists in mechanical disintegration of rhyolite. In summit areas rhyolitic débris to some extent protects parent rock much as obsidian débris does but the slope of the fragmental materials is less steep in the case of the rhyolite. Where stream erosion or cliff recession is taking place rapidly rhyolite tends to outcrop as cliff exposures.

It is essentially because of the differences between obsidian and rhyolitic débris that obsidian areas tend to become summits as differential erosion takes place. If the obsidian of the Warner Range represents seven distinct vents, these vents are now isolated summits because of the protection against erosion afforded by the débris blankets. If the obsidian is all that remains of a flow which had a very irregular base, its present restriction indicates a similar effectiveness in resisting erosion. In any event it appears that the obsidian areas will remain as salient features so long as any of this material remains in the Warner Range.

QUATERNARY SEDIMENTS

The final chapters of the stratigraphic history of the Warner Range are written chiefly in terms of sedimentation similar to that which is taking place at present. The material resulting from sedimentary processes now taking place may be classified as follows:

Lake Deposits and Valley Filling; Mantle Rock and Float; Wind-blown Sand.

LAKE DEPOSITS AND VALLEY FILLING

The deepest Quaternary sediments known to exist in Modoc County are found in Surprise Valley, where a well has been drilled to a depth of 835 feet without reaching their base. This well, located in the town of Cedarville and within a mile of the Warner Range base, encountered sediments which appear to be of lacustrine origin, at least for the most part. That the lake waters remained shallow during most of the period of deposition is indicated by the great amount of organic material, for the most part reeds and coarse grasses, contained in the sediment. The organic material was encountered to the base of the well. Other wells, in some instances half as deep as the Cedarville well, report similar conditions. Gas produced by the decomposition of the organic materials has, very unfortunately, caused a number of persons to hope that petroleum will be found in the valley.

The graben west of the Warner Range, except in its northern middle portion where the Pitt River is now actively cutting a channel, is at present a site of sedimentary deposition. In the northern part of this graben Goose Lake is building up a sedimentary floor of unknown thickness. From a point about five miles northeast of Alturas to the slopes of South Fork Mountain, at the lower end of the graben, sediments have collected in what was in all probability an old lake basin, filling it and converting it into a large area of meadow land. The depth of sediments is not well known. In the vicinity of Alturas, however, wells often pass from lake sediments to underlying bedrock at depths of less than 100 feet. South of Alturas the upper sediments are quite commonly characterized by thick layers of peat. Fires in this material are said, in some cases, to have burned for months and to have required extensive flooding to extinguish them.

The largest filled lake in the Warner Range is found in Jess Valley. The old lake, Lake Jess,²¹ has long since been drained by the cutting of an outlet gorge but wells drilled in the valley indicate that a minimum of 60 feet of lacustrine material collected in the basin before filling to the level of the present outlet occurred. It is said that the amount of organic material found in the lower sediments is relatively small but that toward the top it becomes much greater. This probably indicates that the old lake was relatively deep and

²¹ Russell, R. J., *Landslide Lakes of the Northwestern Great Basin*. Univ. Calif. Publ. Geog., vol. 2, pp. 231-54, 1927.

that in the final stages of filling it approached the meadow condition now prevalent in the valley. Jess Valley is at present largely a flood plain of the streams flowing across it. Spring floods are now responsible for active sedimentation on the floor of the valley. As the outlet stream is flowing with steep gradient just outside of the valley area it will soon deepen its channel to the extent required for removal of some of the valley filling.

Long Valley, about four and one-half miles east of Jess Valley, is coated by a thin veneer of lake sediments which formed in a short-lived lake once occupying it. The outlet stream cut a channel which not only drained the lake but which has been responsible for the removal of a large portion of the sediments as well. Near the outlet miniature bad lands have formed in the old sediments. The organic content of these beds is very low, possibly indicating that meadow conditions were at no time well established in the valley.

Some interesting sediments have collected in Pine Creek basin, in the central part of the range. The basin itself resulted from head-water erosion assisted by sapping action. The outlet is frequently dammed by landslide materials so that an interesting history has taken place in regard to the development of a number of lakes in succession. The sediments here are for the most part white clays derived from Upper Cedarville tuff which outcrops conspicuously on the walls of the basin.

In the northern half of the range thin veneers of dark sediments, derived from underlying Warner basalt, cover portions of Benton Meadow, Halls Meadow, and the meadow north of the principal forks of Davis Creek. Benton Meadow is still subject to occasional flooding, and deposits of white salts are conspicuous shore-line markers on the blocks of black basalt strewn irregularly about its floor. The other two areas have long since been tapped by outlet streams so that flooding is no longer possible except where a small depression in the western part of Halls Meadow collects a foot or so of standing water at times.

At the head of the south fork of Davis Creek a small lake was formed by faulting. Here about ten feet of white and gray clay, derived from rhyolite, collected. Davis Creek, the outlet stream, has maintained an antecedent channel across the uplifted block to the west and has prevented the lake from ever being more than ten or fifteen feet deep. Any inability of Davis Creek to deepen approximately at the rate of uplift would have caused the lake to overflow into

Surprise Valley through Pawley Creek, but this possibility at no time materialized. Davis Creek is rapidly removing the lake sediment and at present has its task more than half completed.

In Fandango Valley a lake was formed by the upwarping, or arching, of basalts across the mouth of the valley. The history of this water body was quite short. The amount of upwarping was slight and the outlet stream, or streams, soon drained the lake. A very thin layer of stratified lake sediment covering the flat basalt sheet of the valley seems to be all that is left to bear record of the existence of the old water body. These sediments will long remain in Fandango Valley in spite of their thinness. Headwater erosion is checked by basaltic talus as tributary gullies attempt to form. Not enough Upper Cedarville material is present above the base level of the valley streams to create a favorable condition for removal of the basalt by sapping action.

The existing lakes of the range are sites of sedimentary deposition at present. Lost Lake has been filled to a very considerable degree, its delta now occupying fully three-fourths of the former area of the lake. The delta at the head of Clear Lake has not advanced so far but at least an acre of sand and well developed natural levees extending out fifty feet or more testify to the activity of Mill Creek South in filling the basin. At Patterson Lake relatively little filling has taken place because of its situation almost at the summit of the range, but even here long talus slopes from the surrounding cliffs and a small delta at the base of a short ravine at the south end of the lake are at work filling it.

Materials collecting in the valleys are for the most part either in the form of fans or cones. Few of the main streams are aggrading their channels at present because the uplift of the range has taken place so recently. Tom Creek is the principal exception to this general rule, or at least has been so in the recent past. A long fan extends up almost to the summit of the range in Tom Creek Valley. Owing to recent rejuvenation this fan is now undergoing a sort of feeble dissection. Another exception to the rule is found in Lassen Creek. This valley has not been subjected to as great uplift as the range area south of it. In it the basalt rests only slightly above the level of the basalt in Fandango Valley, just to the north and northeast. As the gradient of the stream is quite gentle, a stretch of about four miles, east of Sugar Hill, has been subject to rather rapid aggradation. At present there are a number of beaver dams

across the stream and a considerable amount of sediment is lodged behind them. The step-like arrangement of old flood plains in this valley suggests that a similar mode of accumulation of sedimentation has occurred in the past.

MANTLE ROCK AND FLOAT

The character of mantle rock and float is greatly influenced by the character of the bedrock of an area and varies considerably from place to place. The climatic conditions are such that mantle rock and float tend to be composed of angular rather than of rounded fragments, this the result of both dryness and high altitude.

The expression of weathering on the plateaus and other flat areas of Warner basalt is the detachment of rather large slabs or blocks from the underlying rock and the gradual disintegration of the detached masses. It is probable that wind removes the finer products of weathering so that there is very little vegetation on such areas. Slope wash is ineffective in the porous lava caps and few gullies are present. Fine sand and mud accumulations are comparatively rare; apparently they are being removed by some agency now active, probably wind action.

Around the borders of lava caps vertical cliffs (rim rocks) ordinarily form as the result of ease of detachment of blocks along vertical planes in the rock. Often columnar structure is noted. The detached masses are ordinarily of fair size, blocks several feet in diameter being not unusual and blocks a foot or so across being very common.

Below areas of basaltic rim rock, talus accumulates if the initial slope is less steep than the angle of repose of the basalt blocks. Numerous measurements were taken as to the slope of free basaltic talus, the highest values being 33° and the lowest about 20° . As underlying rock surfaces characteristically have lesser slopes than these, they are commonly overwhelmed by talus accumulation.

A good example of this is to be seen on the western side of Warner Valley. While the capping of Warner basalt is relatively thin in that area its débris so thoroughly covers the Upper Cedarville beds that only careful search will reveal their presence. It is likely that this condition caused Waring²² to indicate a great thickness of basalt in the cliffs west of Warner Lake while in actuality the flow is rela-

²² Waring, G. A., U. S. Geol. Surv., Water Supply Paper 220, pl. 10, 1908.

tively thin. Basaltic talus seems to disintegrate slowly. It thus tends to grow upward to the rim rocks and in reaching them serves as an effective check against their removal.

The intercalated andesites of the Cedarville series weather much after the fashion of the Warner basalts. Each flow tends to become an individual rim rock and to collect a talus slope beneath. The Middle Lava Layer, the most important lava accumulation in the Cedarville series, presents these characters to the most striking degree. Its dip slopes resemble similar dip slopes of basalt, being characterized by slabs in various stages of disintegration. Its eastern edge always develops cliffs to some degree, but in several places, as for example in the area northwest of Cedarville or west of Eagleville, it has reached a maximum, producing cliffs almost as high as the layer is thick. The numerous, relatively thin, flows of andesite in the Davis Creek area develop these characters to a lesser degree.

Upper Cedarville agglomerates tend to weather out into a landscape covered by pinnacles. If a source of block or slab talus exists above, the pinnacles often rise island-like above a sea of talus. If no source of talus exists the covering of the areas between pinnacles depends largely upon the slope angle. The Cedarville series as a whole tends to weather into relatively coarse sand, plus either angular or round pebbles from the agglomerate or conglomerate facies. These materials will remain in quasi-equilibrium only upon slopes much more gentle than the slope angles of repose of basaltic talus. On slopes greater than 20° they are commonly removed more rapidly than formed, hence such slopes are characteristically free from slope wash, and fresh bedrock then forms the floor between pinnacles. While this condition is quite common in various parts of the range it is particularly striking in the vicinity of Cedar Pass. On more gentle slopes, free from a source of basalt talus material, débris from the Cedarville beds often builds up into deposits of considerable thickness. Where the slope is less than 10° such deposits remind one of the extensive pavements of desert areas. The upper surface is composed almost entirely of pebbles and larger fragments, sand and finer materials being conspicuously absent. In small stream gullies, or by digging downward a short distance into such a deposit, one finds that the layer of pebbles and coarse material is a superficial characteristic, apparently an expression of wind action in removing sand and allowing the coarser materials to settle until such time as they form a protective cover, thereby checking the rate at which the sand is blown away.

The mantle rock and float of obsidian and rhyolitic areas has already been described. Where equal amounts of rhyolitic and basaltic material fall to form a single talus slope it is always true that the basalt will predominate over the rhyolite in that slope. Even where a large exposure of rhyolite and a relatively small exposure of basalt are contributing to the building of float, slope-wash, or talus, this same generalization holds true. The north fork of Davis Creek drains an area almost wholly capped by rhyolite. In the stream we find many blocks and numerous pebbles of basalt but fragments of rhyolite are comparatively rare. This is an expression of the fact that rhyolite decomposes comparatively rapidly. Splitting and peeling along the thin flow structures is so pronounced that detached fragments are comparatively short-lived, soon being reduced to sand in which condition it is readily blown or washed away, or at least is inconspicuous. The basalt, on the other hand, persists for a much longer time as boulders or large-sized spalls. Large fragments of obsidian break up readily but small chips and fragments last almost indefinitely. Stream beds below obsidian outcrops appear to be lined almost entirely with obsidian fragments even though the outcrop area of rhyolite is many times as large as the source of the obsidian.

WIND-BLOWN SAND

No conspicuous areas of dune sand, or other aeolian deposits exist in the Warner Range. In Surprise Valley, however, such deposits are extensively developed along the eastern side and southern end of the valley. The presence of sand and the absence of loess is an expression of dryness and of the fact that winds remove the finest accumulations from the basin entirely. It is also probable that wind is responsible for the removal of much salt from the saline efflorescences of the playa lakes in the valley.

SOILS

Stoner and Goldsmith²³ classify the soils of flat areas of the Warner Range as heavy black adobe and that of the slopes as volcanic ash or sand. They report that the soil is rich in plant food but that it is generally so thin that it dries out in summer and therefore needs irrigation. It is probable that the dark color of the soil covering

²³ Stoner, S. N., and Goldsmith, B. C., Land classification of the Warner Mountains project, Modoc National Forest, California, MSS. in the San Francisco Office of the U. S. Dept. Agr., Forest Service, Ferry Building.

flat areas is in part an expression of climatic conditions permitting an annual grass crop though dry and cool enough to prevent anything but very slow decay of the roots added to the soil each year. There is considerable contrast between the relatively dark colored soils of the western side of Surprise Valley and the much lighter soils on its eastern side. As the bedrock from which the inorganic content of the soil is derived is the same on the two sides of the valley the difference observed seems to depend upon organic content. The native vegetation of the relatively well watered western side differs widely from that of the dry eastern strip.

STRUCTURAL GEOLOGY

MAJOR FAULTS

The distribution of the major faults of the Warner Range are shown in figure 11. The topographic base used in making this map, a portion of the Alturas Quadrangle, is, unfortunately, inaccurate in many respects. The Forest Service map, used for areal geology, could not be used for the representation of faults because of its limited extent, the major faults often being outside of the territory mapped. Faults are shown as full lines where they have been followed out and as broken lines where they have not. No attempt has been made to indicate the width of fault zones. Most of the lines are far too wide, according to scale, for the faults they represent, but at places along the main faults east and west of the range, fault zones are actually wider than the lines representing them. Little attempt has been made to indicate sharp angles in fault lines. On account of the topographic generalization which is characteristic of the base map it was felt that similar generalization should be used in plotting the faults because greater exactness as to surface trace would mean little, or nothing, without topographic expression. A detailed survey was made of a portion of one fault and is discussed later. In figure 11 each fault is numbered in such a way that odd numbers mean escarpments facing eastward, even numbers escarpments facing westward.

In the paragraphs following, each fault is considered separately and field evidence which led to its recognition is presented. Conclusions based upon this evidence are given in a later section of this report treating of orogenic history.

Surprise Valley fault system.—The Surprise Valley fault (1) is the most important displacement on the map. It was the only fault

in this area mapped by Russell,²⁴ who described it as a "line of profound displacement, which has resulted in the upheaval of one of the grandest of the Basin Ranges." Russell also recognized the continuation of this fault in the area west of Duck Flat. He noted that at Eagle Peak the displacement amounts to "at least 4000 feet" and stated that "when studied more accurately it will probably be found [that the Surprise Valley fault forms] a branch of the Warner Lake zone of displacement, and that it may have other connections with the interlacing fractures of the Great Basin." The writer has checked this prophetic statement and finds it to be true. The escarpment west of Sand Pass, in the Black Rock, or Smoke Creek Desert, traces northward, past an important branch toward the northeast near the mouth of Buffalo Cañon, into the escarpment west of Duck Flat. It then follows the eastern side of the Warner Range, past branches at the northern end of Surprise Valley, and continues on into Warner Valley, where it has been recognized and in part mapped by Waring.²⁵

The maximum displacement on the Surprise Valley fault appears to have taken place in the vicinity of Eagle Peak, as Russell pointed out, but instead of a 4,000-foot displacement a value of 6,000 feet, as a minimum, comes nearer the truth. This is shown on the accompanying section (fig. 2) across the range in the latitude of Cold Peak. The profile used in making this section was surveyed by the writer using a small field transit.

The lines along which the vertical displacement of the Cold Peak area took place are for the most part hidden by talus, slope wash, and lake sediments. At least four minor faults of this zone are west of the main escarpment and are indicated on the Cold Peak section. One of these faults is expressed topographically as a small cliff on the spur followed by the line of the section. All of them have stratigraphic expression, particularly evident in the offsetting of a conspicuous layer of white tuff just above the Middle Lava layer. The offsets, all less than 100 feet, are too small to be mapped on the geologic map.

Recent escarpments near the range base probably mark the location of the main fault lines of the Surprise Valley zone. One of these is shown in figure 12, a photograph of the range base a short distance north of the line of the Cold Peak section. Several similar escarpments are found farther east toward the valley and probably give us

²⁴ Russell, I. C., U. S. Geol. Surv., Fourth Ann. Rept., pp. 449-50, pl. 84, 1884.

²⁵ Waring, *op. cit.*, pl. 6, 1908.

some idea of the width of the fault zone, which locally amounts to about a quarter of a mile.

South of the Cold Peak area the Surprise Valley fault swings toward the southeast so as to pass east of the abrupt slope just west of the resort known as Menlo Baths. At a rather sharp turn near the mouth of Emerson Cañon the Bear Camp fault (19) branches off and runs in a southerly direction to the eastern side of Buck Mountain South. The Surprise Valley fault again bifurcates near Menlo Baths.



Fig. 12. Recent fault escarpment, southwest of Eagleville.

The main branch (1 E) leads along the base of steep escarpments to the base of Buckhorn Mountain. Warner basalt caps the top of the mountain and also forms the cap of the block below, east of the fault. West of Snake Lake another branch (1 D) separates two areas of Warner basalt, the eastern area having been depressed. The block upon which Snake Lake rests has been tilted toward the west so that the lake formed at the base of the escarpment to the west. The easternmost branch of the Surprise Valley fault (1 C) is the line separating the Snake Lake block from the main valley floor. The escarpment between these two areas is particularly fresh. North of Bear Creek it is straight for about four miles. Numerous hot springs emerge from its base. South of Bear Creek the fault takes an easterly direction almost as far as the Duck Flat outlet of the valley, it then turns

south and southwesterly and appears to join the Buckhorn Mountain branch (1 E) in the area west of Duck Flat.

The evidence for faulting as the agency producing the escarpments of the southern part of the Surprise Valley fault is chiefly stratigraphic. This is an area capped nearly everywhere with Warner basalt. The western dip slopes, leading to the southern end of Pitt River Valley, are capped by this material. In the fault zone individual blocks are practically always capped by the same sheet. Beneath the basalt Upper Cedarville beds are commonly exposed.

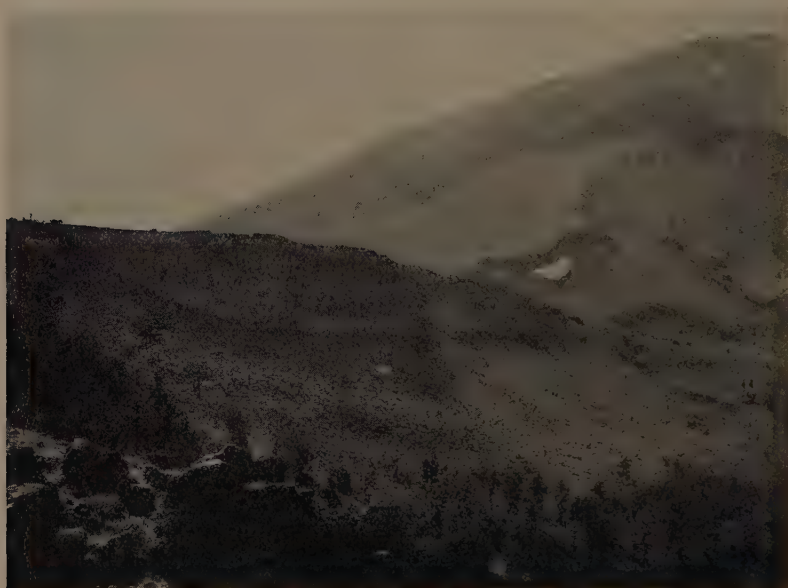


Fig. 13. East Creek fault at range crest just south of Eagle Peak. Warner basalt caps the downthrown block in the center of the view.

Where branch faults intersect, the basalt cap of the block between them ends. The Snake Lake block is at least 3,000 feet lower than the range crest above it. The hot springs at the base of the escarpment east of this block are distributed along a straight line at the immediate escarpment base. This is good contributory evidence of faulting. Recent escarpments running up and down over topographic irregularities at the range base still further strengthen the conclusion.

Two important branches of the Surprise Valley fault leave the line between Eagle and Cottonwood creeks. The more southerly of these, the East Creek fault (17), was studied with considerably more care than was the northern, or Mill Creek fault (15 A).

The East Creek fault is shown on the geologic map as the southern boundary of the lowest cartographic unit, the Lower Cedarville. Lower Cedarville beds actually outcrop farther south, east of the area included on the map, and are shown at the base of the Cold Peak section.

The vertical displacement which took place on the East Creek fault at its point of departure from the Surprise Valley line amounts to at least 1,000 feet. This is expressed as an apparent horizontal offsetting of the upper beds of the Lower Cedarville of about a mile.



Fig. 14. East Creek fault escarpment viewed toward the north from the summit of Bear Mountain. Warner basalt caps both the upthrown block at the distant skyline and the large, more nearly flat, downthrown block of the foreground and middle distances.

Eagle Creek follows this fault for a considerable distance but, owing to the presence of a dike near the northern end of the block south and east of the fault, it leaves the line of faulting abruptly, turning east along the dike. The fault, after being left by Eagle Creek, continues in its northeasterly direction and joins the Surprise Valley fault just south of the small cañon known locally as High Rock Cañon, just west of Eagleville.

At the headwaters of Eagle Creek the East Creek fault passes southwestward across the range crest. As shown in figure 13, it separates the Warner basalt into two parts. The southern part of the basalt caps the downthrown block, and is shown very conspicuously in the picture. The northern, upthrown, part of the basalt caps

Eagle Peak, the highest point shown in the figure. The vertical displacement at the range crest slightly exceeds 1,000 feet. The escarpment between these two blocks is well shown in figure 14 and is again present in figure 15.

After passing west of the range crest the East Creek fault swings gradually toward the south. Its magnitude is lessened in that direction. At Long Valley, seven miles south of Eagle Peak, it forms the gentle escarpment west of the valley and the vertical displacement is in the neighborhood of 250 feet. Though not mapped, the fault was



Fig. 15. East Creek fault viewed from Long Valley. The dip slope left of Eagle Peak (in the center of the picture) and that of the downthrown block (at the right) are both capped by Warner basalt. The subdued escarpment at the left of the foreground is a part of the same fault.

followed south into Cedar Cañon in Lassen County. In figure 2 it is the third fault west of the summit of Cold Peak.

The Mill Creek fault (15 A) branches from the Surprise Valley fault near the mouth of Owl Creek. It was not studied in the range front area below the 7,250 foot level in Owl Creek basin. Apparently the vertical displacement is quite small, probably not over 100 feet, in that area. At the range crest the vertical displacement is slightly more than 100 feet. About three-quarters of a mile after passing over the crest the fault branches, the eastern branch running in a southerly direction along the dip slopes east of Saddleback, the western branch determining the course of the north fork of Mill Creek South above the meadows.

The eastern branch of the Mill Creek fault forms the escarpment of a curious hill of Warner basalt which rises above the normal dip slope of the northern part of the Saddleback block. It is certain that this fault dies out before reaching as far south as Eagle Peak; for the dip slopes there are unbroken from the summit to the vicinity of the south branch of Mill Creek South. In all probability the fault extends farther south than it has been mapped, as a more or less linear group of small hills exists in its continuation as far as the northern summit of Saddleback.

The western branch of the Mill Creek fault (15 B) is followed the greater part of its length by Mill Creek South. As in the case of the eastern branch the upthrown block is west of the downthrown block. The maximum vertical displacement occurs opposite Upper Mill Creek Meadows and amounts to about 400 feet. For most of its length this fault separates blocks capped by Warner basalt but toward the south this capping layer has been largely removed by erosion. A small branch of this fault occurs near the headwaters of Mill Creek South in the area where the direction of the fault changes from southwest to southerly. This small branch is really an expression of the tendency to continue in a southwestern direction and is responsible for a large slump which has offset a considerable area of basalt.

Farther south the Mill Creek fault becomes the western boundary of a small area known as Poison Flat. At this place the vertical displacement amounts to 250 feet. In the Cold Peak section this is the first fault east of Jess Valley. Poison Flat is the basalt-floored depression just east of the fault. On the north wall of East Creek Cañon, just south of Poison Flat the fault plane is clearly exposed and dips east at 60° . Farther down the slope it is obscured by slope wash and agglomerate outcrops. In the bed of East Creek, just about where the fault would be located if projected south, an excellent exposure of a fault plane occurs. This fault plane dips 72° east. Of course it is not certain that this fault plane actually represents the Mill Creek fault as it cannot be traced far in either direction from the stream bed because of thick slope wash. It appears to be a rather important fault, however, as the gouge material is a foot or more in thickness. Since it appears in massive agglomerate the direction of movement is not clearly indicated. If the fault plane exposure is really the Mill Creek fault it is possible that the steeper dip at the stream bed is a fact of some significance in connection with the orogeny of Basin Ranges. But it may simply indicate variability of dip taking place in a longitudinal direction along the fault.

The Bear Camp fault (19) is very similar to the two faults just described. It branches off from the Surprise Valley fault a short distance north of the mouth of Emerson Creek. This area is just south of the Cold Peak section. Viewed from the area south of Eagleville this fault is particularly striking because it marks the southern end of exposed Lower Cedarville beds. These beds are greenish in appearance while the Upper Cedarville beds in contact with them east of the fault are reddish. A small gully is working back along the fault at its northern end. After passing over a low hill the Bear



Fig. 16. Bear Camp fault escarpment viewed to the north from Bear Camp Flat. Bear Mountain, from whose summit the view in figure 14 was taken, is the distant peak at the right. The downthrown block of the Bear Camp fault is the third major successively lower surface of Warner basalt south of the Eagle Peak block.

Camp fault determines the course of the south fork of Emerson Creek to the range crest just south of Bear Mountain. East of Bear Mountain the vertical displacement is at least 900 feet but the value cannot be stated accurately because of the absence of Warner basalt on the downthrown block. Bear Camp Flat is an alluviated area, probably underlain by basalt, on the downthrown block south of Bear Mountain. The Bear Camp fault forms an abrupt escarpment west of it. This area is shown in figure 16. It is a question whether the topographer who made the Alturas Quadrangle ever saw this area; if he did he failed to indicate it. The photograph and the Forest Service map differ widely from the Quadrangle here. South of Bear Camp Flat the fault escarpment dies out rather rapidly. It can be traced, with the eye, from the summit of Bear Mountain to the east side of

Buck Mountain South, where it is responsible for a slight irregularity, the downthrown block forming a small bench, but nowhere does the vertical displacement approach the values in the Bear Mountain area.

One other small fault, the Camp No. 1 fault (21), was noted in the southeastern part of the range. This fault appears to have no interlacing connections with the Surprise Valley fault system. It forms an escarpment about 100 feet high just west of Camp No. 1 Flat, and an escarpment about 25 feet high on the south side of Silver Creek, southwest of Lost Lake. Apparently it dies out rapidly both to the north and south. Warner basalt occurs both above and



Fig. 17. Fault escarpment near headwaters of south fork of Davis Creek.

below the escarpment but the displacement is so slight that it cannot be shown on the geologic map.

North of Owl Creek, for about 20 miles, no branch faults extending into the range were found. There are a number of sharp turns in the Surprise Valley fault. At several places observations were made as to the dip of the fault plane. Numerous recent escarpments occur at the range base. Ten miles of this distance was studied in great detail, a survey of the range base and of recent escarpments was conducted, and numerous observations were made. The description of this area is included in the next section of this report.

South of the area marked by the absence of branch faults all of the faults leaving the Surprise Valley fault leave toward the southwest. North of that area branches leave toward the northwest. This is one of the most striking features of the fault pattern of the range.

At the headwaters of the south fork of Davis Creek is one of the freshest appearing and straightest escarpments in the whole range (see fig. 17). At the southern end of the area shown in the figure Warner Basalt caps both the upthrown and downthrown blocks, the vertical displacement being about 200 feet. Farther north the basalt is capped by rhyolite which is similarly displaced. The fault was traced into one of the branches of the north fork of Davis Creek and there lost in Upper Cedarville agglomerates. It is probable, however, that the northwestern direction of the longest branch of the north fork is an expression of erosion along the continuation of this same line. Toward the south the fault was lost in Upper Cedarville



Fig. 18. Fandango Mill fault, in Fandango Valley looking southward. The fault passes southeast over the range crest near the center of the picture.

beds but was picked up again in Pawley Creek, where it offsets the Middle Lava Layer, and again was lost in the Lower Cedarville, below the elevation of 5,600 feet. There is a distinct topographic suggestion that it joins the Surprise Valley fault at the mouth of Wilkerson Creek but this could not be demonstrated stratigraphically.

The Fandango Mill fault (5) meets the Surprise Valley fault just north of Goose Creek. The vertical displacement at the intersection is more than 1,000 feet, expressed topographically by the low range crest to the north and geologically by the failure of Lower Cedarville beds to outcrop north of the intersection. At the range crest the vertical displacement is about 500 feet. Upper Cedarville beds are here exposed in the escarpment face. Both blocks are capped by Warner basalt. Exposures of Upper Cedarville continue for about seven miles as the fault follows the south fork of Fandango Creek

and the south side of Fandango Valley past the mill. Toward the northwest the escarpment gradually disappears, its end being in the area between Lassen Creek Valley and Fandango Valley, near the mouth of the latter. Figure 18 is a view of this escarpment, looking toward the southeast in Fandango Valley. In the distance the profile of the escarpment at the range crest is shown. The valley floor consists of Warner basalt for the most part; locally it is covered with a fine veneer of lake sediments but the main stream cuts through to the basalt. The upthrown side is similarly capped by the basalt, which forms a dip slope down to Lassen Creek. On the downthrown block,



Fig. 19. Surprise Valley fault zone viewed toward the north near the Fandango road.

at the head of the valley, the basalt is folded so as to form a dip slope leading to the lower range crest shown at the left of the figure. The south fork of Fandango Creek approximates the position of the fault but lateral cutting has thrown it west of the fault, at places as much as several hundred feet. This fault is particularly interesting in that it almost succeeds in extending the whole distance across the range.

North of the Fandango Mill fault the Surprise Valley fault zone widens. Here a number of blocks, generally basalt or rhyolite capped, make up a step-like displacement of 2,000 feet or so. The largest individual escarpments rarely exceed a third of this figure. A typical view of this area is shown in figure 19.

The most instructive fault plane exposure of the whole Surprise Valley fault was found on the second stream south of the Fandango road, as shown on the Forest Service map. This stream is midway between the Fandango road and the crossing of Heath Creek on the Lake City road. The location is one-half mile east of the National Forest boundary. Here there are a number of conspicuous calcite veins running in various directions but a strike of $N 13^{\circ} W$ is most common. This strike can be followed for some distance across several small spurs and ravines, indicating that, at least over a considerable area, the rocks are in place. In one of the widest veins evidence of displacement is found in slickensided and polished surfaces of the rocks bounding the vein. Striae on these surfaces are confined to the plane of $N 13^{\circ} W$, $54^{\circ} 30' E$, and pitch $40^{\circ} N$ with regard to a horizontal line on the strike of the fault plane. This indicates that the western block has not only been upthrown but also that it has moved toward the south, with reference to the block east of the fault, the southerly component being somewhat greater than the vertical. While numerous planes indicating normal faulting were found in the Warner Range this was the only locality in which the horizontal component of motion could be established in quantitative terms. It appears that the calcite followed some older plane of fracture before the movement just described took place, so of course the striae found here do not necessarily represent the direction of movements during the whole history of faulting, they simply indicate the direction of the last movement on this particular fault plane.

In the vicinity of Fort Bidwell the Surprise Valley fault divides into two or three main branches. Russell²⁶ recognized this in his mapping of the Surprise Valley fault by showing one branch east and another west of Mount Bidwell. While studied only from adjacent summits there is a strong topographic suggestion that the fault west of Mount Bidwell extends to the north, east of Mount Vida, and that it branches at least once toward the northwest.

The branch of the Surprise Valley fault east of Mount Bidwell (1 A) was traced to the north as far as the town of Plush, in Warner Valley. On the eastern slopes of Mount Bidwell it was studied with considerable care and was found to form a zone in which at least six blocks are involved in the vertical displacement. The summit of Mount Bidwell is capped by 250 feet of rhyolite, the Warner basalt being beneath. The basalt-rhyolite contact is repeated on four of

²⁶ Russell, I. C., U. S. Geol. Surv., Fourth Ann. Rept., pl. 84, 1884.

the six fault blocks. The two lower blocks are covered by rhyolite and are so small that the basalt is not exposed. Stratigraphic evidence and a few fault plane observations indicate an average dip of 60° E for the fault planes here. Farther north the rhyolites become thinner although the typical sequence as far north as the road summit between Twelve and Twenty Mile creeks consists of rhyolite at the top, basalt next, and brownish tuff, baked red at the basalt contact, passing downward into typical red Upper Cedarville agglomerate beneath. The thickness of the basalt is less toward the north. At Mount Bidwell it is 500 feet; near Adel, in Warner Valley, it is less than 100 feet; and farther north is generally less than 30 feet but not constantly so. Obsidian fragments, from some source not discovered, are abundant toward the south but grow fewer toward the north. On the slopes at the southern end of Warner Valley frequent repetitions of the stratigraphic sequence are caused by faulting along the Surprise Valley fault zone. Fault planes, with dips varying from 55° to 73° , were found in several instances. All of the fault planes dipped eastward and are clearly related to the Surprise Valley fault system.

Lake Annie, just north of Surprise Valley, is situated in a small graben bounded by the Surprise Valley fault on the west and a smaller fault (2) on the east. Apparently the small eastern fault is the more active of the two. Its escarpment is particularly fresh, being an almost plane surface dipping 40° toward the west and free from anything but the slightest beginning of erosional modification. Lake Annie hugs this escarpment closely.

Cedar Peak fault.—So far as is known the Cedar Peak fault (11) has no direct connection with the Surprise Valley fault system although the movement which has taken place on it has been of the same general character. This fault is shown on the Cedar Peak surveyed section just east of the summit (fig. 2). On the south side of Cedar Peak the fault plane is a clearly cut zone of brecciation, 6 to 8 inches thick, dipping eastward at 55° . The strike is practically north and south in this area.

South of Cedar Peak the fault seems to determine the course of the north fork of Tom Creek and it is probably related to the steep slopes south of the Alturas-Cedarville highway summit, east of Payne Peak. In this area Upper Cedarville agglomerates and flows are badly weathered and often brecciated in quite a wide zone, all of which may very possibly be related to movements on the Cedar Peak fault. The fault could not be definitely traced in this area and could not be found farther south toward Squaw Peak.

North of Cedar Peak the fault passes just east of the summit of Bald Mountain. On the steep slopes north of this summit it is very distinct and much like the exposure on Cedar Peak. Farther north it passes out into an area of agglomerate, often covered by slope wash, and could not be traced. It is clearly present in that area, however, as shown by the displacement of Warner basalt in figure 20. The difference in elevation between the flat summit of basalt, shown at the right of the figure, and the sheet covering the flat-topped hill and its extension to the right, indicates a displacement of about 500 feet,



Fig. 20. Cedar Peak fault near headwaters of Lake City Mill Creek. The downthrown block (near the center of the picture) is capped by Warner basalt, as is the summit area north of Bald Mountain (at the right).

vertically. At the headwaters of Lake City Mill Creek the fault swings toward the northwest. As shown by displacement of basalt, there is a decided tendency toward dying out in that direction. After leaving the area still capped by basalt the fault points directly toward Franklin Cañon and seemingly is responsible for its straight course. It could not be definitely followed in that area, however, because of valley filling, float, and the presence of gentle slopes of agglomerate.

Sugar Hill fault.—The Sugar Hill fault (7) is situated at the eastern escarpment of Sugar Hill and parallels Lassen Creek for several miles. The displacement on this line is comparatively slight, the top of the Warner basalt east of it being less than 100 feet lower than the top of the basalt beneath the rhyolites of Sugar Hill. The

prominent escarpment itself is for the most part the edge of the rhyolite, very little of that material occurring to the east. It seems probable that a branch of the Sugar Hill fault passes on the east side of the hill near the Ranger station, close to the Lassen Creek sawmill, and accounts for the straight course of the creek in that vicinity. Difficulties in observation, caused by the presence of rhyolitic talus from the slopes of Sugar Hill and also by the dense forest growth plus the fact that very little field work was done in the area, render the mapping of the Lassen Creek area the least accurate on the geologic map. It seems not unlikely that the Sugar Hill fault of this area is connected with the fault (7) traced into the Davis Creek area, if so the feature resembles closely the Fandango Mill fault.

Faults of the southwestern area.—Aside from one small escarpment in the Davis Creek area (13) all of the remaining eastward-facing fault escarpments in the Warner Range are located in its southwestern area. These break up somewhat the regularity of the westward dipping slopes and are responsible for the development of several valleys, the most important of which are Jess and West valleys.

The northernmost mapped fault of the southwestern area is located just west of Cantrall Mill (29). Here the Warner basalt is broken by a differential uplift of from 60 to 80 feet, for the distance of a mile or more. On either side of the fault the westward dip of the basalt approximates 2° . At the base of the escarpment a small meadow has been formed in what was, for a short time, a lake basin. The lake was confined between the fault escarpment on the west and dip slopes on the east. After a comparatively short life its outlet deepened sufficiently to drain it into Fitzhugh Creek.

On the western side of Jess Valley, differential uplift, amounting at a minimum to about 1,000 feet, has taken place in a rather wide zone (23, 25, and 27). The greatest amount of uplift occurred on the fault nearest the valley. Numerous small, unmapped, faults farther to the west are a portion of this same zone. In the Cold Peak section four of these are shown. Traced north and south several of these faults join one another; in fact the whole zone seems to be a closely related feature of interlacing lines.

The streams draining Jess Valley show a decided preference for its western side, flowing at the immediate base of the escarpment rather than in some more central location. This is probably good evidence of the recency of movements in the fault zone. The topographic freshness of the escarpment bespeaks the same idea.

The north and south extensions of the Jess Valley fault zone were not carefully traced. There is little doubt that the Cantrall Mill fault is a related feature to the north. There is also every reason to suppose that toward the south this zone passes Blue Lake on its west side. The escarpment is continuous between Blue Lake and Jess Valley but the writer did not visit Blue Lake itself and did not follow the escarpment far south in Jess Valley.

Jess Valley is similar structurally to the small lake basin at Cantrall Mill. Its eastern side is essentially a dip slope and its western side is a fault escarpment. The Warner basalt has been removed from much of the eastern slope but it is present at the base of the slope and apparently continues down beneath a rather thick deposit of lake sediments which floor the valley.

West Valley is structurally the same as Jess Valley. On its west is the West Valley fault (31) and on its east are dip slopes of Upper Cedarville beds, here and there capped by remnants of the basalt. The basalt at the top of the western escarpment overlies exposed Upper Cedarville.

Numerous small faults, similar to those just described, cut the dip slopes of the southwestern area. These are too small to map, offsets of 10, 20 or 30 feet and less, for the most part being present on breaks a mile or less in length. In practically all cases the escarpments of these small features are east-facing, the faults having approximately north-south orientations. In a few cases the displacement has been enough to expose a thin strip of Upper Cedarville but usually the whole escarpment is composed of basalt. The few springs of the basalt area west of Jess Valley are all related to faults of this nature.

Western fault system.—All of the west-facing escarpments of the Warner Range are connected with a zone of fracture which starts slightly southeast of Alturas and continues at least as far north as North Alkali Flat, about 80 miles north of the Oregon line. Russell²⁷ mapped this fault from a point about 10 miles north of Abert Lake as far south as Antelope Valley, or to within about 19 miles of Lakeview. As his route of travel did not extend farther in either direction than these points he could not have been expected to map the fracture in its full extent. In his text Russell describes portions of this fault most graphically; for example:

The grand cliffs that present an impassable barrier along the eastern shore of Abert Lake expose the broken edges of strata on the heaved side of the fault; while the thrown side underlies the lake-basin and forms the gently sloping western

²⁷ Russell, I. C., *op. cit.*, pl. 84, 1884.

shore. A short distance south of the lake the great fault divides, and sends a branch to the northwestward which determines the northeastern border of Chewaucan Marsh, while the main fault continues on, as we have said, to form the eastern border of Abert Lake. The triangular block included between these two faults inclines to the eastward. . . . Each of the faults bounding Abert Lake has a curved and irregular course, and finally becomes lost in branches as we follow it northward. . . . The palisade rising abruptly from the eastern shore of Abert Lake has a deep brownish tone . . . and is grand in its barren ruggedness. Near the top of the cliffs the hard layer, forming the "Rim Rock," is a conspicuous feature, and in resisting erosion has no doubt done much towards preserving the rough outlines of the cliffs.

It is interesting to note Waring's²⁸ treatment of the portion of the Western fault system in the area just north of the Warner Range. He maps a fault for about twenty miles along the eastern side of the depression containing Alkali Lake and North Alkali Flat. For about seven or eight miles farther south he shows the continuation of the escarpment but does not indicate a fault at its base. In this area the escarpment is not so straight as in that to the north. It is evident from his mapping of other faults that Waring always hesitated to indicate a fault at any place where an escarpment takes any sudden turn, a fact which probably explains the omission in the area in question. Farther south, along the same escarpment, he again indicates a fault, starting it at just about the place where Russell's Abert Lake fault was started and carrying it as far as Antelope Valley, just as far as Russell carried it. Still farther south, on the western side of the Warner Range, Waring mapped the fault from the Oregon line north, past Lakeview, to a point two miles away from the termination of the Abert Lake fault but he does not connect the two, even though the escarpment is continuous between them. This connection would have involved a slight jog in the line. East of Chewaucan Marsh, Waring maps the fault mapped and described by Russell to the extent shown by Russell excepting that, strangely, he fails to connect it with the Abert Lake fault.

South of the Oregon line the Western fault system was recognized by Hill,²⁹ who stated, "The west front of the [Warner] range has an abrupt rise of 1,000 feet above the level floor of Goose Lake Valley. . . . This rise is along a fault which follows the east side of the valley for a considerable distance."

Farther south this fault continues, with one irregular break at the mouth of Fandango Valley, as far south as Pine Creek South, south-

²⁸ Waring, G. A., U. S. Geol. Surv., Water Supply Paper 220, pl. 6, 1908.

²⁹ Hill, J. M., U. S. Geol. Surv. Bull. 594, p. 39, 1915.

east of Alturas. For the sake of convenience the main line of displacement (4, 6, and 8) will be referred to as the Western fault.

At Lakeview the escarpment of the Western fault is about 2,000 feet high. At the top of the range Warner basalt dips eastward into the broad plateau crossed by the road between Plush and Warner Cañon. A few miles north of Lakeview, Warner basalt is found in the floor of Goose Lake Valley. In the vicinity of Lakeview the range base is characterized by low and very recent escarpments. While these often follow straight lines for considerable distances they are not at all adverse to taking sharp turns, as, for example, the turn from north to northwest at Lakeview. So recently has this last uplift



Fig. 21. Western fault north of Fandango Valley, viewed toward the north from the summit of Sugar Hill. The mouth of Fandango Valley is at the right and Goose Lake Valley at the left of the tree-covered area leading toward the escarpment.

taken place that streams crossing the lower part of the upthrown block have been unable to deepen their channels fast enough to keep up with it, falls and steep gradients being common in the vicinity of the fault line.

South of Lakeview the Western fault (4) runs at the base of the Warner Range for about twenty miles, its general direction being southerly. Though numerous changes in the strike of the fault take place two directions are particularly conspicuous, north-south and $N\ 60^{\circ}\ E$. Changes in strike are generally quite abrupt so that the fault line consists of a number of rather short segments, each of which is quite straight in itself. The fault zone is comparatively narrow but near the range base a small amount of step faulting is characteristic.

About twenty miles south of Lakeview the Western fault suddenly swings toward the southeast, passing up the northern side of Fandango Valley. The area in which this bend occurs is shown in figure 21. With the Western fault on its northeastern side and the Fandango Mill fault (5) on its southwestern, Fandango Valley is a graben between two comparatively steep escarpments. Warner basalt caps Fandango Peak, 2,000 feet above the basalt in the valley floor. West of Fandango Peak the basalt is capped by rhyolite. On the south side of the valley the Fandango Mill fault separates the basalt of the valley bottom from that of the Lassen Creek block, but toward the northwest, where the fault dies out, the basalt is continuous between the two areas.

Followed toward the southeast, up Fandango Valley, the Western fault dies out. The escarpment rapidly diminishes in size east of Fandango Peak and at the head of the valley merges into a monoclinal fold. The change (from a condition of tension, indicated by normal faulting on the Western fault northeast of the valley, to a condition of compression at the homoclinal fold at the head of the valley) could easily be accomplished by a slight rotation of the block north of the valley in a clockwise direction, the pivotal area being some distance to the northeast of the valley.

In the area at the mouth of Fandango Valley, Warner basalt is up-arched along a zone representing the southern continuation of the Western fault (4) and connecting it with the Western fault (6 A) on the Goose Lake side of Sugar Hill. Both ends of the up-arched area start out as normal faults in a direction which suggests connection. The northern fault is exposed in the bed of Willow Creek about 200 yards east of the road crossing. The southern fault is the direct continuation of the displacement west of Sugar Hill. In figure 21 the northern fault is not evident, the displacement being only about twenty feet or less. The upthrown block of the southern fault is marked by dense forest growth at the center of the picture. Farther to the right a lesser stand of timber at a lower elevation marks the region of up-arching between these faults. This up-arching temporarily dammed Fandango Valley, causing a lake to form in it. That the lake was short-lived is indicated by the thinness of the veneer of sediments which cover the basalt of the valley floor. Willow Creek succeeded in draining the lake by cutting an outlet, popularly known as the "Cañon," now 50 to 75 feet deep. Lassen Creek cut a similar gorge about two miles farther southwest. There is no evidence of

any lake having existed in its valley, the stream in its antecedent condition seems to have cut as rapidly as the territory was elevated across its valley mouth. The comparatively great depths of the gorges of these two streams, each flowing with gentle gradient, suggests that a considerable amount of time has elapsed since their initiation. Certainly the arched area is much older than the recent escarpments at Lakeview or those in Surprise Valley.

The fault west of Sugar Hill (6 A) has less vertical displacement than the topography at first sight suggests. Most of the escarpment existing there is the edge of the rhyolite, the maximum displacements of the basalt being 200 or 300 feet, dying out rapidly toward the arched area to the north.

Between Goose Lake and the fault west of Sugar Hill there is a broad zone characterized by faults with westward-facing escarpments. The greatest of these is close to the lake shore and has been indicated (4 A) on the fault map. West of the northern end of Sugar Hill (fig. 22) the displacement is at least 500 feet but the basalt is buried in lake sediments at the escarpment base. There is little doubt that basalt is present under Goose Lake. It is exposed on the graben floor at both ends of the lake. At the southern end the old outlet channel into the north fork of the Pitt River is cut almost entirely in basalt. Numerous tilted blocks, capped by basalt and in "floe ice" arrangement, are expressions of differential settling of the graben floor in that area. From a maximum in the vicinity of the mouth of Lassen Creek the displacement on the lake-shore fault grows rapidly less both to the north and to the south. It is not certain that this line can be definitely tied in with the main Western fault in either direction. It is certainly true, however, that this fault is closely related to the Western fault. At the Fandango break, where the displacement on the main line becomes least and finally, for a short distance, is reduced to a small arching of the valley floor, the displacement on the lake-shore fault is greatest. In either direction the lake-shore fault dies out in accordance with greater displacement along the line at the range base.

The fault at the base of Sugar Hill (6 B) swings to the southeast as it approaches the Davis Creek area, farther south it trends in a southerly direction. The displacement is variable from place to place along this line. From 200 or 300 feet in the Sugar Hill area it increases to 500 feet at the north fork of Davis Creek. Three miles farther south, at the south fork, it is about 1,000 feet. At Linville

Creek it is reduced to 500 or 600 feet but at Halls Meadow it again approximates 1,000 feet. For most of this distance the displacement separates basalt on the downthrown west side from Upper Cedarville, capped by the basalt, on the upthrown east side. Below Halls Meadow, as the fault line passes out into Joseph Creek Basin, the displacement is not readily measured for want of satisfactory key beds. In the agglomerates and brush or forest-covered slopes of that area even the position of the fault line is not easily found. Joseph Creek basin has formed rapidly, after the removal of the protective

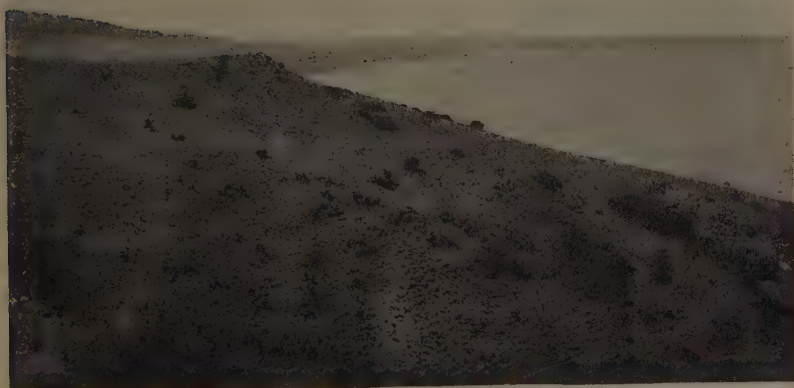


Fig. 22. Lake shore escarpment west of Sugar Hill, looking south-southwest.

cover of basalt by erosion. The western escarpment has receded more rapidly here than toward the north so that the fault is not distinctly outlined topographically. In this uncertain area the fault probably swings southwestward so as to join another line (8) farther to the west. The rapid development of the basin is probably an expression of this bending. The first fault west of the summit of the Cedar Peak section seems to be a branch of this general zone of displacement. Where it crosses the section the displacement is 200 feet or less, but it rapidly dies out toward the south, no trace of it being found on the ridge south of Tom Creek.

The branch of the Western fault (6 B, 6 C) just described, on account of its position east of the range base, is responsible for rather striking modifications of the drainage pattern of the west front of the range. Streams flowing down the slopes from east to west on

encountering the zone of crushed and weakened rock at the fault are likely to be diverted into north or south courses along this zone. The most striking case of this is the diversion of the south fork of Davis Creek. Wind gaps west of Plum Valley suggest that formerly the stream was wholly independent of the north fork and that it probably entered the flat of Goose Lake Valley some distance south of the town of Davis Creek. A branch of the north fork working headward along the fault zone, in the area shown in figure 23, tapped the south fork



Fig. 23. Eastern member of western fault system looking south along the south fork of Davis Creek where it follows the fault. The highest point in the picture, the northwestern end of Benton meadow, is capped by Warner basalt, as are the small hills at the right of the fault.

and diverted its waters toward the north so that they now follow the fault zone for two miles.

The area shown in figure 23 is quite typical of the eastern branch (6 B) of the Western fault system. The camera was pointed south. The downthrown block at the right (west) is capped by Warner basalt. The upthrown block in the distance is the northwestern end of the basalt capping Benton Meadow. The escarpment slopes, beneath the basalt capping, are exposures of Upper Cedarville tuffs, agglomerates, and intercalated andesitic flows.

The southern member of the Western fault system (8) starts several miles north of the town of Davis Creek and runs south along

the western range base as far as Pine Creek South, a distance of about twenty-six miles. The greatest vertical displacement on this fault is in the vicinity of Tom Creek, or just about where it crosses the Cedar Peak section. The vertical displacement here is about 1,500 feet. In either direction it grows less. It is a remarkable view, from a geological standpoint, to see the gradual disappearance of the escarpment of this fault in the area between Tom Creek and Pine Creek South. Toward the north the dying out is somewhat less spectacular. Between Joseph and Franklin Creeks the fault zone is quite wide and the escarpment consists of the western edges of numerous small fault blocks. North of Franklin Cañon the fault zone narrows again and for the last seven miles the vertical displacement is comparatively small, the escarpment rarely exceeding 200 feet in height.

Displacements along the southern member of the Western fault system often involve Warner basalt and are therefore measurable with comparative precision. The fault planes themselves are generally covered by talus and float but on the north side of Tom Creek a number of prospect pits have been dug and some of these expose fault planes, usually dipping westward at about 60°. The representation of the four faults of this zone on the Cedar Peak section is therefore quite exact. At most places Warner basalt is found capping the downthrown block but in the line of this section it is absent over most of the area, probably initially so as the flows surrounding the area thin out in that direction. In this respect this portion of Pitt River Valley resembles the area southwest of Alturas, a few miles away.

The only fault in the Western zone which departs from the general condition of downthrow toward the west is a line about three miles long west of Plum Valley and the small meadow north of the north fork of Davis Creek (13). This line is the eastern boundary of a small horst, probably an expression of differential settling in connection with the general adjustments which took place on the Western fault. The displacement of the east-facing escarpment is 150 feet and less, usually not enough to expose the Cedarville beneath the basalt.

One of the most interesting general observations in connection with the Western fault system is the tendency toward the development of parallel lines and the general rule that small displacements on one of these lie opposite large displacements on the other. For this reason the total displacement between range base and range crest is not as variable from north to south as the height of any particular

escarpment on the range front. In the Fandango area, however, the total vertical displacement is locally considerably less than that along other portions of the fault system. This is particularly evident if the top of the Warner basalt is considered, not the present topography, which is largely the result of rhyolitic accumulation. The upper surface of the basalt is distinctly depressed not only across the mouth of Fandango and Lassen Creek valleys themselves but also to the south as the valleys are approached. This results in a change of strike direction of the basalt, the north-south strikes farther south turning toward northeast-southwest strikes in the rhyolite capped region. The depression of the basalt in the rhyolitic area suggests that a connection exists between the two phenomena. It seems evident that the basalt has not foundered as a result of the removal of rhyolitic magma from reservoirs beneath the surface because this would imply a former high elevation of the basalt. During such elevation the surface of the basalt would have to undergo more or less erosion. The basalt-rhyolite contact is convincing evidence against this assumption. It seems most probable that the rhyolite antedates the period of faulting and that Sugar Hill and associated areas were domes rising above a flat basalt surface similar to the domes rising above the Gardens, a few miles to the west. If a connection exists between the low altitude of the basalt and the presence of rhyolite it seems more probable that the frozen roots of the rhyolites have held the area down. The floor of Fandango Valley itself is free from rhyolite but may owe its low elevation to its being a "shadow" of the rhyolitic area just south. As the fault north of the valley, being a normal fault, slopes toward the rhyolite it would seem probable that a shadow, or protected, or leeward area, should share in protection against uplift afforded by the rhyolite.

RECENT FAULTS IN SURPRISE VALLEY

Russell in describing the Surprise Valley fault stated:

This line of displacement is marked by numerous hot springs and by fresh fault-scarps, from 20 to 50 feet high, that cross alluvial cones, and cut embankments and terraces of Quaternary age, telling in the plainest language that the rocks bordering the line of fracture have been disturbed at a very recent date, and that the Warner Mountains are young, and probably still growing. That the fault movement is paroxysmal is indicated by the earthquakes which are sometimes felt throughout the valley.³⁰

All of these statements were verified with the exception of the last. The people in Surprise Valley were closely questioned in regard to

³⁰ Russell, I. C., U. S. Geol. Surv., Fourth Ann. Rept., pp. 449-50, 1884.

earthquakes and it developed that even the oldest inhabitants have felt very few. Several felt the San Francisco earthquake of 1906. Many felt the Pleasant Valley earthquake of 1915 and a considerable number felt several small shocks, apparently originating near Susanville, in 1918. No earthquakes of local origin seem to have been felt by the present residents.

The plainest indications of recent faulting in Surprise Valley are the escarpments at the bases of the Warner and Hays Cañon ranges. Such escarpments are found most commonly at the immediate range



Fig. 24. Basalt broken and gently tilted toward the range base as a result of recent faulting in Surprise Valley. View toward the southwest at Goose Creek.

base, as shown in figure 12, but in many cases they occur some distance out in the valley, as shown in figure 24. Those at the range base resemble the escarpments on the western side of Carson Valley, in west central Nevada, described and figured by Lawson.³¹ Those found some distance out in the valley bear some resemblance to the edges of gravel embankments of the Lahontan Basin, as described and figured by Russell.³² Though Surprise Valley formerly contained a large water body, Lake Surprise, and though many erosional and depositional features are present around the valley margins, there is an abundance of evidence that the escarpments here described are tectonic in origin.

³¹ Lawson, A. C., The Recent fault scarps at Genoa, Nevada. *Bull. Seis. Soc. Am.*, vol. 2, pp. 193-200, 1912.

³² Russell, I. C., U. S. Geol. Surv., Monograph 11, e.g., pl. 21, 1885.

While most of the small escarpments have been caused by faulting some of them were caused by monoclinal folding. Where such folding could be thoroughly established it was always found that the escarpment slopes are comparatively gentle. In the case of each fold escarpment it was possible to trace it into a fault, in at least one direction.

The fold escarpment shown in figure 25 is located about four miles north of Cedarville. The folded beds are stratified, unindurated sandstones, probably laid down in Lake Surprise. After monoclinal



Fig. 25. Fold escarpment in Surprise Valley, four miles north of Cedarville, showing recent deformation in Quarternary lake sediments.

folding it is evident that these layers were subjected to erosion which resulted in a slight beveling of their upper surface. Later the beveled edges were covered by slope wash from the range, toward the west. The erosion which accomplished the beveling could well have happened at any time in the last few years. It should not be considered as evidence of any special condition, such as the result of wave action or some former interval of tectonic history. The uneven surface of the beveled beds is certainly indicative of stream erosion. Flooding at present causes streams to migrate widely over the valley slopes at the range base. Any particular area in that location is subject to alternating conditions of corrasion and deposition. It is said that the

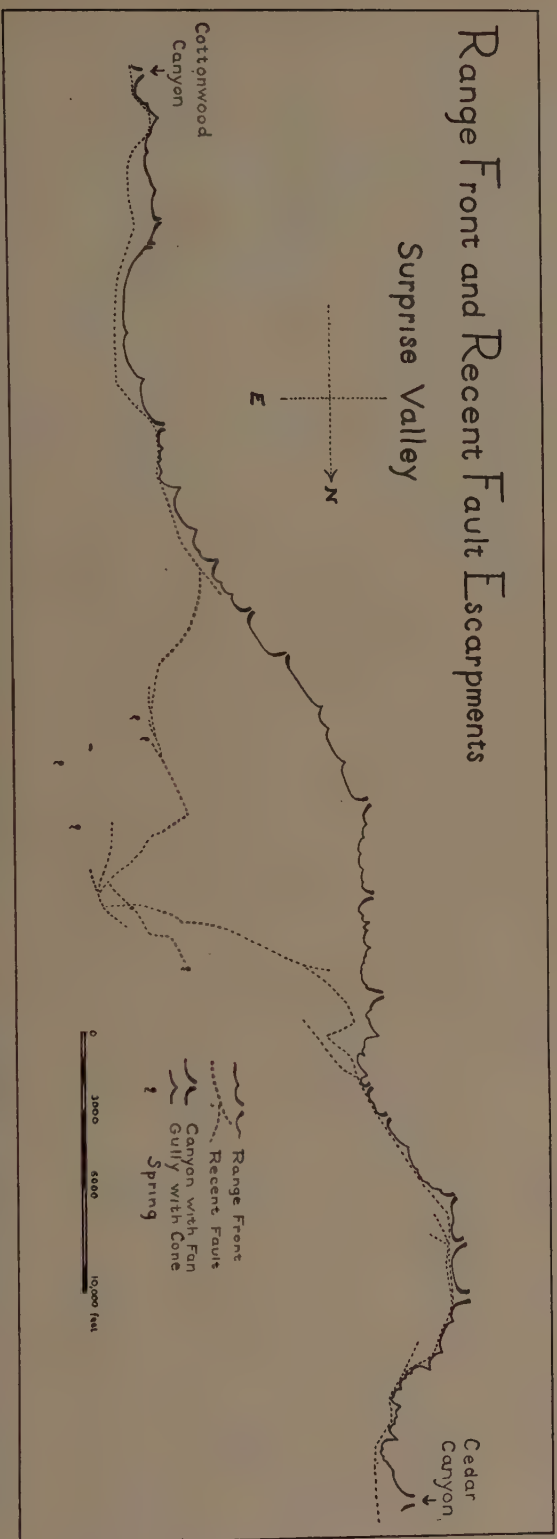


Fig. 26. Plan of range front and recent fault escarpments in Surprise Valley, between Cedar and Cottonwood cañons, taken from the writer's survey of this area by means of a field transit.

gorge which exposed the beds, shown in the figure, was cut during a cloudburst in 1909. (This gorge does not follow the more recent pipe line but takes a downstream course at the left of the photographed area.) The material above the beveled beds is recent float and has not been derived from the sandstone beneath, as indicated by numerous pebbles of andesite and basalt from the slopes above. When this fold escarpment is followed southwest it steepens and merges with fault escarpments at the range base.

The association of hot springs with recent faulting in Surprise Valley was noted by Russell. South of Eagleville many large hot springs issue from the immediate escarpment of the branch of the Surprise Valley fault (1 C). Farther north hot springs are situated out in the valley, generally in distinct relation to lines of recent displacement. Not only hot springs but cold springs as well are usually aligned along recent faults, the most common situation being near the ends of such lines rather than at the bases of pronounced escarpments. Small depressions, largely of zoogenic origin but clearly marking old spring sites, similarly line up along the projections of segments of the recent escarpments.

The portion of Surprise Valley in which the most detailed study of recent fault escarpments was made lies between Cedar Cañon, just west of Cedarville, and Cottonwood Cañon, somewhat more than ten miles farther south. This area was surveyed with a small field transit in connection with this study. The chief results of this survey are presented in figure 26.

The heavy line in figure 26 represents the range base. It is practically a contour excepting that a convention is used to indicate cañon and gully positions. Cañons with alluvial fans are indicated by means of breaks in the line. Gullies, usually with rather steep alluvial cones, are indicated by the denting of the line inward toward the range. Recent escarpments are indicated by dashed lines, each line running along an escarpment base. Springs are designated by means of an appropriate symbol.

Detailed description of the surveyed area.—At Cottonwood Creek the recent escarpment at the range base is indicated by an abrupt oversteepening amounting to a vertical displacement of about 30 feet. This condition continues for about 2,000 feet toward the north. Farther north the recent escarpment leaves the range base but continues roughly to parallel it within a distance of 1,000 feet.

At the gully next north of the point of departure of the recent escarpment from the range base a fair sized alluvial cone has been cut by the recent fault, the displacement being about 30 feet vertically. The small stream emerging from the gully is now building a new cone below the escarpment, the new cone being still smaller than the portion of the old cone upon which it rests in distinct topographic unconformity.

Slightly over a mile north of Cottonwood Cañon two small cañons give rise to a rather complex alluvial fan which is cut by an escarpment 10 feet high at the south but nearly 20 feet high at the north. The slope angle of the escarpment here is 33° E. Beyond this the escarpment strikes almost due north for something over one-half mile, with a vertical displacement of not less than 18 feet and not over 35. The dip toward the east varies between 27° and 42° .

The cañon 13,500 feet from Cottonwood is called Steamboat Cañon. At this place the recent fault is found at the range base. Between Steamboat Cañon and the segment of the fault described in the last paragraph, the fault follows a line striking $N 42^{\circ} W$ and is very straight. The displacement along this segment is similar to but slightly greater than that of the preceding segment, the maximum value being 40 feet. A very small gully (not indicated on the map) just south of Steamboat Cañon has had its cone cut by the fault. The uplifted portion of the old cone is now undergoing dissection and the small stream from the gully is now entrenched 10 feet or so in its old cone.

North of Steamboat Cañon the fault strikes slightly east of north and hugs the range base. The vertical displacement on this segment varies between 25 and 35 feet. The upper angle of the fault escarpment is notched by streams from several small gullies above and the lower angle is being covered by cones.

Just south of the first large gully north of Steamboat Cañon the strike of the fault changes abruptly to $N 19^{\circ} W$ for about 2,500 feet. Farther north it swings to $N 38^{\circ} W$ for a similar distance.

At the first small cañon north of Steamboat (and about 18,750 feet north of Cottonwood) a branch fault is sent off toward the northeast. The escarpment near the range base dies out a thousand feet or so after the branching. About 600 feet south of the dying out of this fault a considerable excavation, for the purpose of developing a water supply, has been made back toward the range from the escarpment face. This exposes a section of rock from the escarpment

back for 60 feet or more. Where the excavation has been made the escarpment is 15 feet high and dips eastward at 30° . The rock exposed is folded monoclinally so that the dip of the homoclinal element approximates very closely the dip of the escarpment face. The rocks exposed here are similar to those shown in figure 25, consisting of finely banded sandstone for the most part.

For nearly 20,000 feet north along the range base there are no recent escarpments. This portion of the range base is interesting, however, in regard to the main Surprise Valley fault. At Mill Creek, the next cañon north of the dying out of the recent fault, one of the best exposures of a fault plane was found. This was visible on both sides of the cañon, practically at its mouth. The attitude of the fault was $N\ 37^{\circ}\ W$, $54^{\circ}\ NE$. Slight drag effects were visible in beds of white tuff and considerable brecciation was noted in several agglomerate layers. In the next cañon north of Mill Creek another exposure was found in which the fault had a similar strike but an eastward dip of 64° . Both of these are regarded as exposures of one of the main faults of the Surprise Valley fault zone.

The branch fault which swings away from the range base, near the excavation, curves rather gradually away from the strike of the range base into a strike direction of $N\ 45^{\circ}\ E$. In this curvilinear part the escarpment height increases from 10 feet, near the excavation, to 20 feet where the strike is northeast. The change of strike into that of $N\ 10^{\circ}\ E$, in the next segment, is relatively sharp. At the turn the vertical displacement is about 20 feet but on the $N\ 10^{\circ}\ E$ segment, in a distance of 1,500 feet, it increases to 70 feet.

Three small branches leave the recent escarpment as it makes its next turn, from $N\ 10^{\circ}\ E$ to $N\ 25^{\circ}\ W$. The southernmost of these branches meets the main escarpment where it is 75 feet high. At the next branch it is almost 100 feet high. At the northern branch the recent escarpment reaches its maximum height, 150 feet. The southern two branch faults have comparatively little vertical displacement in themselves and augment the main escarpment only about eight or nine feet. Each of these faults dies out within 1,000 feet after leaving the main escarpment. The northern branch fault has a 15-foot vertical displacement as it leaves the main line and though it dies out as rapidly as the other two it seems to be a more important break as two springs are located along the projection of its strike. Beyond the branches the main escarpment is very straight for 2,500 feet. The vertical displacement grows less toward the north and is 75 feet at the end of the segment.

At the northern end of the N 25° W segment the recent escarpment takes an abrupt turn, practically a right angle, to a strike of N 62° E. After running in this general direction for about 4,500 feet it reaches its greatest distance from the range base, about two miles. The vertical offset remains constant at about 65 feet in this segment.

For the sake of convenience the end of the uplifted salient to the east will be called East Point. The small escarpment which bounds East Point and which also extends some distance north and south will be called the Eastern Escarpment.

At East Point the main line of uplift turns at nearly a right angle into a strike of approximately N 17° W, swinging into the line of the eastern escarpment. A branch escarpment to the south is situated between the main line and the eastern escarpment. The vertical displacement on this branch escarpment is 15 feet at the place of branching and dies out in 2,500 feet. The eastern escarpment leaves East Point toward the south as a cliff 20 feet high but dies out in about 1,000 feet. Two cold springs are situated on the projection of this line, the first being 2,650 feet and the second 5,200 feet from East Point.

Just north of East Point the eastern escarpment is 65 feet high. Beyond the N 17° W segment the eastern escarpment has a strike of N 52° W, which it holds for about 1,000 feet. The displacement is 10 feet where the segment begins but this dies down to three or four feet in a short distance so that most of this segment is very inconspicuous. About 1,000 feet north of East Point the main escarpment leaves the eastern escarpment and turns sharply toward the west.

A cross-fault cuts the nose of the large salient toward the east about 900 feet west of the place where the main escarpment leaves the eastern escarpment. This cross-fault appears to be more recent than the salient itself. Its slopes appear to be very fresh and the surface of the salient is offset 15 feet on its northern side. This offset runs down the northern slope of the salient and out into the valley flat beyond for about 1,300 feet, with a strike of N 29° W. At the end of this segment the cross-fault swings into a strike of N 86° W for 1,200 feet and finally turns again into a strike of N 27° W, in which direction it dies out. The vertical offset on this escarpment is about eight feet as it swings down the north side of the salient and diminishes to five feet at its last turn. Beyond the last turn it fades out into a depression formed zoogenically around a flowing spring of cold water. In the line of projection of the last strike several similar

depressions are found but they do not contain springs. It is probable that these are old spring sites but that flowage of water has been stopped by the trampling of animals. The spring which still flows happens to be at the intersection of the projection of the cross-fault and of the projection of the eastern escarpment. This was the only case where a spring location seemed to be determined by fault intersections and may be only a matter of coincidence.

Just west of the cross-fault on the eastern salient the face of the main escarpment has been locally modified by a large slump. The salient block consists of lake sediments, gravels and sandstones for the most part, quite unconsolidated but somewhat cemented together by lime. Prior to slumping, the escarpment face was about 75 feet high. A block about 1,000 feet long and 400 to 500 feet wide moved downward and northward so as to leave behind it a more or less continuous valley about 40 feet deep. Slope wash from the adjacent slopes has partially filled the valley, the filling being irregular so that the floor is divided into several small basins along its axis. These depressions contain miniature playa lakes which do not overflow, partly because of the small amount of rainfall the region receives and partly also because of the porosity of the materials beneath. It is likely that the slump occurred at the time of cross-faulting and is another bit of evidence that the cross-fault is more recent than the salient. On the map, the slump area is shown as if bounded by a concave escarpment on the south. This line is the inner side of the small valley. The slumped mass is north of the line.

Beyond the slump the main escarpment continues toward the range base and for nearly 5,000 feet approximates a strike of N 70° W. In this segment the vertical displacement decreases from about 65 feet to about 35 feet toward the range. At the end of the segment a southern branch starts toward the range but dies out in about 800 feet. The vertical displacement along this branch is small, being only about 5 feet at the junction. Beyond the branch the main escarpment curves rather gradually into a strike of N 48° W to the crossing of Granger Creek. Just south of the creek-crossing the escarpment is about 30 feet high.

North of Granger Creek (slightly more than 36,000 feet from Cottonwood Cañon and 19,500 feet from Cedar Cañon) a small salient is formed between segments striking N 69° E and N 45° W. At the end of this salient is the sharpest angle on the whole of the survey. The vertical displacement on the southern segment of the

salient is about 10 feet and that of the northern segment averages 15. At the end of the northern segment the fault is close to the range base, a location which it keeps until it intersects the small ridge just south of Cedar Cañon. Where the escarpment joins the range base it receives a branch from the southeast. This branch is 3,200 feet long and strikes N 38° W for most of its length. Its displacement is small, averaging about 5 feet, and it dies out to the southeast.

Between the last branch described and the ridge south of South Deep Creek (10,000 feet from Cedar Cañon), the escarpment is simple and hugs the range base closely. In 4,000 feet of the 6,600 feet of this segment the fault strikes N 32° W. In the remaining distance the departure from that direction is always less than 5° and is usually within 3°. The vertical displacement along this segment varies between 10 and 15 feet.

In the bedrock of the range front along the straight segment just described there are two exceptionally clear exposures of fault planes. The first of these is in the small cañon just northwest of the branching fault escarpments. In this cañon, practically at its mouth, several small parallel offsets are exposed. The largest of these has a displacement of about six feet. Each offset is marked by a thin zone of brecciated rock which has become somewhat silicified and stands out for that reason. The dips of these zones are similar, approximating 63° E. The second exposure was found in a small gully about 2,500 feet farther northwest, or about 700 feet beyond the second small cañon above the branch fault. Here a zone of brecciated rock, from three to 12 inches thick, dips eastward at 65°. The amount of offset could not be estimated because of the absence of key beds. Both sides of the fault were flanked by Lower Cedarville rocks. It is not supposed that any very great displacement took place upon any of these faults. They are very instructive, however, in suggesting the dip angle of the Surprise Valley fault zone as a whole.

At the mouths of the Deep Creeks, the two large cañons next south of Cedar Cañon and not over 10,000 feet distant, two recent escarpments run north and south for about 3,400 feet. These are shown at the right of figure 27. The vertical displacement has been about eight or ten feet on each line. These lines join at North Deep Creek, beyond which the escarpment remains simple for most of the distance to Cedar Cañon.

At South Deep Creek two branches join the main escarpment. As shown in the photograph, the main escarpment is situated some

distance up on the range front; it is particularly evident at the left of the view, below the cañon. The vertical displacement amounts to nearly 20 feet in the area at the left of the picture but grows less toward South Deep Creek. The southernmost of the branch faults strikes $N 28^{\circ} W$ and, though its total length is only about 1,000 feet, reaches a maximum displacement of from 30 to 35 feet in the area shown in the figure. The second branch fault strikes $N 60^{\circ} W$, is about 700 feet long, and the escarpment is only four or five feet high. This line appears as a very thin streak in the picture.



Fig. 27. Mouth of South Deep Creek Cañon, southwest of Cedarville.

North of North Deep Creek the recent escarpment strikes $N 23^{\circ} E$ for about 2,100 feet. This line is simple and straight, passing upward and downward over alluvial cones at the base of the range, with a general displacement of about 20 feet everywhere. The second segment leaves the first sharply and strikes $N 64^{\circ} E$ for about 1,100 feet. Another sharp turn brings the line into a strike of $N 27^{\circ} E$. At this bend it is joined by a branch from the south. The main escarpment is 40 feet high north of the branch and the branch itself is 12 feet high at the junction. The branch dies out in 1,300 feet.

In the remaining distance to Cedar Cañon, about one-half mile, the fault takes two more sharp turns, dividing it into three segments. The northern and southern of these strike about north and south, the middle one $N 30^{\circ} E$. The displacement approximates 30 to 40 feet for the entire distance. Toward the north the fault is removed some 200 feet from the range base but farther south it hugs the base closely.

Just south of Cedar Cañon, and very accessible for observation, a small gully is forming at the upper angle of the escarpment, the removed materials being deposited as a cone just below. While a number of these features were observed, nowhere was one seen which so closely resembled an idealized textbook diagram as does this one.

Several generalizations are warranted as the result of the above study:

1. The recent escarpments show a decided tendency to hug the range base and to change direction with changes in direction of the range base but they do not do so invariably.
2. Where the escarpments hug the range base the vertical displacement is usually less than when they are some distance out.
3. The segments of the recent escarpments are usually quite straight and tend to meet at rather sharp angles, although exceptions to both of these observations occur.

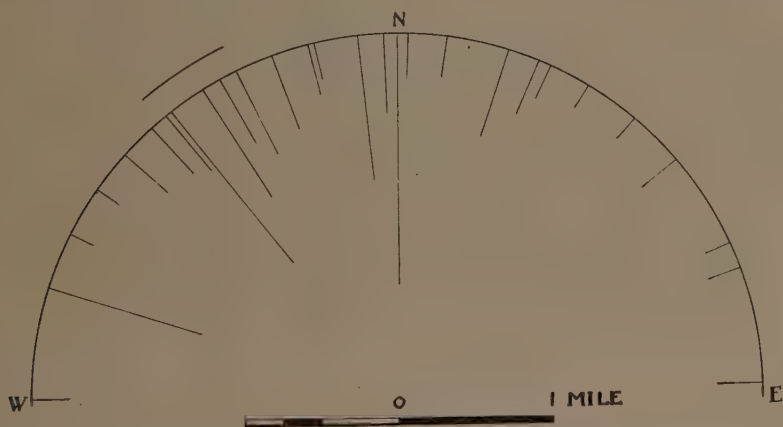


Fig. 28. Strike directions and distances along segments of recent escarpments between Cottonwood and Cedar cañons in Surprise Valley.

4. In the area surveyed, the recent escarpments and the range base show a preference for strike directions of north and south and also for strikes within 7° of $N\ 33^\circ\ W$. Strikes approximating these directions are repeated, though occurring widely apart, as if there were some structural control conditioning them. The accompanying diagram, figure 28, indicates this for the recent escarpments.

5. Branch faults are relatively common, usually occurring in the neighborhood of rather sharp bends.

6. Springs are likely to be located in line with segments of the escarpments but some distance away, where the escarpment is feeble, or unexpressed topographically.

7. There seems to be no, or at least little, connection between strike direction and amount of displacement.

Escarpments outside of the surveyed area.—The selection of the strip between Cedar Cañon and Cottonwood Cañon for detailed study was a random choice, made principally because of the central position of that area, and was in some ways unfortunate. The large salient in the center of the strip was not considered when the choice was made, in fact it was not known that this feature would come into the study. Any other ten-mile strip would have suited the purpose of the study equally well; several choices might have suited it better.

If the ten miles north of Cedar Cañon had been selected it would have contained several large salients, including the one in the range front itself which forms the eastern end of the Cedar Peak section. A ten-mile strip north of Lake City would have contained more area in which the recent escarpments stand out from the range base. If, in the southern part of the range, a ten-mile strip north of Menlo had been selected, the positions of the shore lines of Lake Surprise could have been indicated and the fact brought out that the highest shore line is always well above the highest recent escarpments. In this regard the Cottonwood-Cedar Cañon strip was an unfortunate selection because in that area the shore lines are not particularly well preserved. Another unfortunate fact about the area studied is that Warner basalt is nowhere found at the base of the range. It seems desirable, in view of these shortcomings, to present data from other localities in regard to recent faulting in Surprise Valley. So far as the writer knows a detailed study of any of these other areas would have yielded data for the same generalizations which resulted from the Cedar-Cottonwood Cañon study.

In the area north of Lake City it is quite generally true that Warner basalt occurs at the range base and that it is cut by the recent escarpments. The main uplift on the Surprise Valley fault is responsible for the break between the basalt at the range summits and that on the valley floor. The recent faulting has contributed to this separation but is most evident in connection with breaks which occur in the basalts of the valley floor. In figure 24, a photograph taken near the mouth of Goose Creek, the basalt is shown broken by recent faulting. The upthrown block has been slightly tilted westward, so as to slope gently toward the range. Both hot and cold springs are found in association with recent faulting in this area. They are generally found in connection with salients which project far out into

the valley. The absence of springs along escarpments at the range base in this area is similar to that observed in the more carefully studied area.

While the area north of Fandango road was not studied in sufficient detail to map it, evidences of recent faulting were noted as being particularly clear because Warner basalt is almost always involved in the displacements. A portion of this area is shown in figure 29. While several comparatively recent escarpments are shown in the picture, a small one in the middle distance is particularly instruc-



Fig. 29. Recent escarpments cutting Warner basalt in the Surprise Valley fault zone north of the Fandango road.

tive for the reason that it occurs wholly in the basalt and runs up over a larger salient (similar to the cross-fault near East Point in the surveyed area). The area north of Fandango road is in reality a mosaic of blocks, practically all basalt capped, cut into an intricate pattern by small interlacing faults. Basal oversteepening of the escarpments, hardly touched by erosion, testifies as to the recency of the last movements. Springs associated with these faults are relatively numerous and cold water issues from them. As a number of rather deep stream gorges cross this interesting area it should prove a fertile field for the study of fault plane dips. Exposures are almost certainly frequent enough to warrant a study of statistical nature.

Hanging valleys are common on the Surprise Valley front of the Warner Range and also along the streams draining that slope. The hanging valleys of the front are almost certainly an expression of

uplift beyond the power of vertical corrasion in the main streams. The hanging valleys of the stream channels are an expression of the greater cutting power of the master streams in response to a lowering temporary base level. The tributaries are often left far behind in the matter of downcutting and in many cases their discordance is such as to produce waterfalls. Thus either directly, or indirectly, movements at the range base are responsible for the hanging valleys.



Fig. 30. Surprise Valley front with recent escarpment salient at range base, view toward the south from a point three miles north of Cedarville.

At the extreme right of figure 30 a hanging valley just northwest of Cedarville is shown. Below this is the recent escarpment of one of the long salients, dipping very gently toward the range. All along the range base oversteepening, resulting in a truncated appearance of spur ends, is very evident. The highest point in the picture, Buck Mountain, is capped by Warner basalt which dips toward the west with almost unbroken slopes and joins the flows exposed on the mesas just southwest of Alturas. The various elements of ridge profiles, described under the heading "Topography," are clearly shown in this picture. It is impossible to explain the various features here shown without recognizing the Surprise Valley fault and it is also impossible to explain the features at the range base without recognizing the rôle of recent uplift of the range block, or depression of the valley area at its base.

It is probable that a detailed study of the hanging valley elevations on the Surprise Valley front would shed light upon the longitudinal

differential uplift of the Warner Range block. The recent escarpments indicate that uplift takes place more rapidly at one place than at another. Evidence from hanging valleys would probably warrant some quantitative conclusions extending back over a greater interval of time. This study would be complicated, however, by the varying sizes of hydrographic basins of the streams flowing down the hanging valleys. The hydrographic basin of the small stream which flows down the hanging valley shown in figure 30, for example, is very small. This stream is dry for the greater part of each year. Vertical corrasion is accomplished only at the time of floods and much of the energy of the stream must be spent in transporting *débris* which accumulates in its channel between intervals of activity. On account of the small amount of vertical cutting accomplished by this stream the valley elevation is much higher than that of Cedar Cañon, just

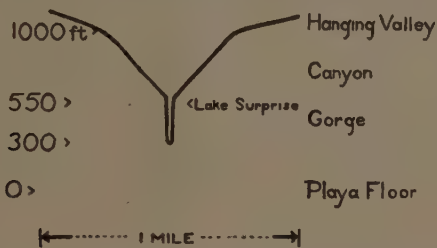


Fig. 31. Diagrammatic profile across Eagle Creek in the Gorge area.

to the south. Cedar Creek, in keeping up with the elevation of the range block, which it is able to do largely as a result of its large hydrographic basin, cuts down so rapidly that most of its tributaries, at least toward the range base, enter it discordantly. The hanging valley study would have to take into account not only the elevation of valleys hanging on the range front but also the valleys hanging above the master streams.

Near the range base the withdrawal of Lake Surprise has caused erosional rejuvenation similar in many respects to that due to active uplift. A number of streams, possibly Emerson Creek is the best example, have entrenched themselves in their old deltas and former flood plains. The most striking case of entrenchment, however, is found on Eagle Creek and is illustrated diagrammatically in figure 31.

Eagle Creek gorge, shown in figure 32, reminds one of the deep chasms which lead out to the gorge of the Columbia River, east of Portland. Above the gorge, and nearly 1,000 feet above the level of the southernmost large playa in Surprise Valley, there is a clear

remnant of an old hanging valley. In the floor of this old valley Eagle Creek has entrenched itself in distinct topographic unconformity, forming a cañon about 400 feet deep. The bottom of this cañon is just about at the elevation of the highest, and apparently most permanent, level of Lake Surprise. That a temporary base level remained at that elevation some time is indicated by the slope of the



Fig. 32. Eagle Creek Gorge.

cañon walls. With the withdrawal of the waters of Lake Surprise, Eagle Creek entrenched itself below the old cañon and cut its present gorge. This gorge is now just the width of a dike which it follows. Several rather large waterfalls in the gorge indicate that the stream is actively cutting downward at present. Little or no widening has taken place in the gorge under the cañon. Apparently the cañon represents the widening of a small gorge cut in the upper portion of the same dike now being followed. That this widening represents a halting stage in downcutting is indicated by the fact that the gorge

walls are sheer cliffs 300 feet high in distinct unconformity with the cañon walls above. While an acceleration of uplift might give rise to a similar condition, the circumstantial evidence of the similarity between the level of Lake Surprise and the level of the cañon argues strongly for rejuvenation as the result of lowering levels of the old lake.

Hays Cañon range.—Recent escarpments, similar to those at the Warner Range base, occur along the eastern side of the southern half of Surprise Valley at the foot of the Hays Cañon Range. Basalt and sometimes basalt capped by rhyolite is often involved in the recent faulting. In other cases lake terrace deposits, alluvial fans and cones, and alluvium are cut. Both hot and cold springs are found in association with the fault. Several large and apparently quite recent slumps on the range face are possibly results of recent movements. Hanging valleys are the rule on the Hays Cañon range front. Several beautiful examples occur just northeast of the old Duck Flat Valley outlet. Allowing for a slight climatic difference, the Hays Cañon Range being drier than the Warner Range, the west front of the Hays Cañon Range is very similar to the east front of the Warner Range. The same stratigraphic section is exposed and the history of uplift seems to have been strikingly similar.

*Surprise Valley lakes.*³³—The distribution of the lakes in Surprise Valley is interesting from the standpoint of recent faulting.

At the northern end of the valley Lake Annie hugs a very recent escarpment upon which practically no erosion has taken place. The floor of the graben between this escarpment and Mount Bidwell slopes toward the escarpment.

South of Fort Bidwell, Upper Lake is located between the Warner Range on the west and a number of very small fault block hills on the east. The lake hugs the range base despite the fact that it "has been carved by stream erosion, and sculptured by rain, wind, and frost, into deep recesses, outstanding pinnacles, and lofty domes"³⁴ and that the sediments derived from this erosion must rest, for the most part, at the range base.

Surprise Valley becomes a graben farther south, as shown by Russell's³⁵ sketch sections. The front of the Hays Cañon Range is nearly as high as that of the Warner Range and the lakes, as if to maintain a strict neutrality, lie centrally between the range fronts.

³³ Russell, R. J., *The Land Forms of Surprise Valley, Northwestern Great Basin*. Univ. Calif. Publ. Geog., vol. 2, pp. 323-58, 1927.

³⁴ Russell, I. C., U. S. Geol. Surv., Fourth Ann. Rept., p. 449, 1884.

³⁵ Russell, I. C., *loc. cit.*, p. 450.

These lakes are rather large playas, however, and their floors are not perfectly flat. As the dry summer advances the winter accumulation of water evaporates and it becomes evident that the floors of the basins are tilted gently westward so that the last standing waters are found along their western borders. This condition is found despite the fact that sediment is carried freely into the playas by Warner Range streams, whereas, across the valley, a zone of sand dunes prevents a large part of the Hays Cañon drainage from ever reaching the playa floors.

The association of lakes with steep escarpments, even though the escarpments are deeply eroded, implies rather active rotation of the blocks upon which the lakes rest. It seems probable that the recent escarpments near the range bases are an expression of this rotation.

SUMMARY OF OROGENIC HISTORY

Pre-faulted surface.—In discussing the stratigraphy of the Warner Range and its surroundings, emphasis has been placed upon the remarkable degree of concordance which exists between all the rocks found in that area. Throughout the Cedarville period of andesitic accumulation layer after layer collected to form a series of rocks at least 7,500 feet thick and essentially concordant from base to top. At the end of this remarkable history a thin, but very widespread flow of basalt covered the upper surface of the Cedarville beds. Merriam, in describing a portion of this area, states, "If the lava sheet were removed, the sedimentary beds beneath would form a nearly level plain" and, in referring to the basalt, "It is difficult to understand how a flow could extend itself so broadly."³⁶ The present study has noted that many basaltic dikes occur in the Warner Range area and that some of these lead directly into flows of Warner basalt, establishing the fact of fissure eruptions, at least for the part of the area studied most carefully. The stratigraphy of the basalt suggests most strongly that it was laid upon an almost flat surface and that the upper surface of the flows formed another essentially flat surface. If the original altitude of this surface were definitely known it would form an ideal datum for the study of uplift and depression in connection with the recent tectonics of the area.

³⁶ Merriam, J. C., Univ. Calif. Publ. Geol., vol. 6, p. 38, 1910.

Gardens datum.—The Gardens is essentially a flat plateau capped by Warner basalt. Later acidic rocks have covered small areas of the basic surface but the areal extent of the relief features resulting from them is small. Farther west the Warner basalts have been covered with later basic rocks and the Warner basalt surface is entirely obscured. In the uncovered surface of the Gardens approximately 2,000 square miles of Warner basalt lies at an elevation of between 5,000 and 5,200 feet above sea level. Whether this represents the original level of the top of the basalt or not is a question which possibly can never be answered, but in any event, such widespread distribution at such uniform altitude suggests strongly that it does. Whether or no, this area serves as a convenient datum to which relative displacements may be referred. In the following description this level will be used and for the sake of convenience will be called the Gardens datum.

Though the Gardens area as a whole is remarkably flat and uniform in regard to altitude it is not free from small faults. Lines of displacement cut it in various directions but the most common strikes approximate north and south. North of the Gardens, across the Oregon line, similar faults outline small Basin Ranges. In the Gardens, displacements exceeding 50 feet are rare. All the faults appear to be quite recent. The cumulative effect of these displacements does not result in any progressive increase in altitude in any direction, the whole Gardens surface maintains its general similarity in altitude irrespective of the small faults.

Departures from Gardens datum.—Immediately east of the Gardens is the Goose Lake graben. Waring, in describing the northern end of this structure, says that "Goose Lake Valley lies, as it were, on the dropped keystone of an arch."³⁷ This condition is certainly true at the Oregon line and for some distance north. Farther south, however, the graben is flanked by the Warner Range on the east but on the west lies only the edge of the Gardens, a flat plateau.

The Goose Lake graben structure continues to the south at least as far as Tule Lake Mountain, at the southern end of Pitt River Valley, and possibly farther, into the Madeline Plains.

The western fault of the Warner Range flanks the graben on its eastern side as far south as Pine Creek South. In the vicinity of Alturas, in Pitt River Valley, other small faults west of the Western fault separate mesa surfaces of Warner basalt from the sediments

³⁷ Waring, G. A., *op. cit.*, p. 26, 1908.

of the south fork of the Pitt River, and this condition continues, with few interruptions, as far as Tule Lake Mountain. One of the interesting interruptions of this general condition is found about four miles north of Likely. Here the basalt dips gently westward below the sediments of the valley meadow.

The fault west of Goose Lake outlines the eastern extent of the Gardens for most of the distance to Alturas. Below the Pitt River, at Alturas, this line of fracture is continued in a relatively narrow zone to the south. West of Likely this zone widens and a number of interesting blocks capped by Warner basalt are found in its interlacings. The complicated structure of Warm Springs Valley and the area southwest of Alturas is probably related to branches from this fault system.

The northern part of the Warner Range is essentially a horst, capped by Warner basalt which has been elevated above the Gardens datum 2,000 feet and more. The upper surface of this block tilts eastward north of the Oregon line. South of Fandango Valley it tilts westward but large parts of it are very nearly level. In the section surveyed across Cedar Peak it will be seen that a small upward concavity is displayed. This condition begins in the Davis Creek area and extends as far south as the ridge just south of Tom Creek.

With the dying out of the Western fault the Warner Range changes from a horst, toward the north, to a tilted block, toward the south. Where the summits are highest the upper edge of the basalt is some 4,800 feet above the Gardens datum. From this loftiest region the basalt extends, almost without a break of any sort, down dip slopes to the mesas of the south fork of Pitt River Valley. The writer would welcome an opportunity to show this territory to some of the opponents of Basin Range structure. Jess Valley, West Valley, and other small interruptions of the regularity of these slopes exist farther south but the region west of Buck Mountain is remarkably free from faults within the range area.

The eastern boundary of the Warner Range and the western boundary of the Surprise Valley graben is the Surprise Valley fault. Basalt occurs on blocks associated with this faulting at various elevations down the range front and along the western side of the valley bottom as well. The lowest altitude of basalt in the graben is not known but a definite maximum can be set for one area. The deep well at Cedarville encountered lake sediments down to an elevation of less than 4,000 feet above sea level. This is over 1,000 feet

below the Gardens datum and nearly 6,000 feet below the basalt at the summit of Eagle Peak, a few miles away.

The region east of Surprise Valley is for the most part a plateau. At the north the rise is comparatively gentle and irregular from the valley to the plateau but toward the south it occurs in a narrow zone at the Hays Cañon Range front.

The Hays Cañon Range presents a front much like the Warner front across the graben. The same stratigraphic section is exposed and the same basalts cap it except where it is locally covered by rhyolite. The altitude of the basalt east of Eagleville is about 2,000 feet lower than the altitude of the Warner basalts across the way, the Hays Cañon Range summits approximating 7,000 feet in elevation. At Cedarville the two summits are more nearly the same altitude. Warner basalt is found in the valley at the base of the Hays Cañon Range at a number of places.

The plateau east of the Hays Cañon Range tilts gently toward the east. Altitudes of 7,000 feet are the rule at the west of this plateau but 45 miles farther east they tend to approximate 6,000 feet. Extensive plains occur on this plateau which remind one of Merriam's description of the extension of this area toward the north.

The surface of the table presents a most unusual spectacle, . . . The lava is covered by irregular patches of soil in which no plants larger than sagebrushes have developed, . . . The evenness of the surface and the unvarying nature of the long stretches of sagebrush and lava blocks are such as to make a judgment of distance most difficult.³⁸

The plateau east of the Hays Cañon Range has been broken to some extent by faulting and has been dissected by a few deep stream gorges. The most important structural break is Long Valley, a graben about 60 miles long and 1,000 feet deep. The most important stream gorge is High Rock Cañon, with walls which rise as sheer cliffs nearly 1,000 feet high as a maximum. Despite such spectacular irregularities the unity of the plateau area is impressive and creates a lasting image in the mind's eye when viewed from some of the surrounding summits. The grabens and gorges in it are clearly of second-order importance.

The eastern side of the plateau just described is bounded at its southern end by the northern arm of the Black Rock or Smoke Creek Desert, which extends up to Soldier Meadows. In this area the Warner basalts, with more or less rhyolitic covering, dip gradually eastward and finally disappear beneath the deposits of the desert

³⁸ Merriam, J. C., *op. cit.*, p. 37, 1910.

flat. Farther north the plateau ends at Summit Lake and from thence, at the base of the Pine Forest Range, the boundary gradually winds around into the escarpments south and west of the Thousand Creek country.

Warner arch.—In the foregoing paragraphs a huge arch has been described. From west to east this passes from the Gardens to the summits of the Warner and Hays Cañon Ranges and across the plateau to the east, finally ending, as it reaches the desert. For the sake of convenience this will be referred to as the Warner arch in subsequent description.

The Warner arch is not only a topographic feature but is a structural feature as well, as the rock of which it is composed is concordant with the surface. The crest of the arch is asymmetrically placed near its western extremity. Several grabens break the continuity of the profile of the arch. The largest of these is Surprise Valley, at the arch crest. The second largest is Long Valley, not far east of the crest. Goose Lake graben is situated at its western extremity and apparently another graben bounds it at the east, this feature being suggested by the desert flat, the flat north of Soldier Meadows, and other depressed areas farther north. Near the eastern boundary is High Rock Valley, another small graben. From the Gardens, Warner basalt can be traced across the whole of the arch, up on the highest elevations and down into the lowest grabens. The axis of each graben parallels that of the Warner Arch itself, in its north-south direction.

Longitudinal profile of Warner Range.—In addition to the east-west Warner arch uplift the Warner Range gives evidence of arching from north to south, suggesting that the whole of the basalt-covered area involved in Warner arching is in reality a huge dome.

Summit elevations are greatest in the central part of the Warner Range. Toward both north and south they are less. Such an effect might readily be explained on the basis of north-south compression, resulting in a warping or doming of the area. In the case of the Warner Range, however, the longitudinal arching represents differential uplift of blocks separated by normal faults. The highest summit area is the central block. Toward the south a number of branch faults leave the Surprise Valley fault zone and separate blocks of lesser and lesser elevation. North of the central block other branch faults produce the same effect. Bearing in mind that all of the branch faults are of the normal type, a study of the Fault map

(fig. 11) will show that the blocks south of the central summits must have an apparent motion of south as well as down from the central block and that the apparent motions of blocks north of that area are down and north. The slickensided fault plane of the Surprise Valley fault in the northern area agrees with this idea. No fault plane exposures contradict it. The evidence of block movements clearly indicates that a condition of north-south tension has existed in connection with the range displacements and certainly refutes any notion that longitudinal arching is the result of horizontal compression in that direction.

The pattern of the Surprise Valley fault system is particularly significant in its relationship to direction of movement. Sharp bends and numerous salients are characteristic at the base of the high central block. Here the movement apparently has lacked any horizontal component in the general direction of the fault line. Both north and south of this block, however, the segments of the main fault are strikingly straight. Aside from the broad, smooth, regular bends at their branching from the main fault, and from each other, the breaks between the northward and southward moving blocks are also straight. One of these is well shown in figure 17. Thus in the areas where lateral displacement is known to exist the fault lines are straight.

Force involved in displacements.—The geophysical question of the origin of the force, or forces, which produced the Warner arching and general doming of the area under consideration will not be considered here. The direction taken by such force, or forces, however, comes well within the scope of geological conclusion.

All the displacements which have taken place in the Warner arch area can be explained on the basis of differential vertically acting forces. So far as the writer is aware they cannot be explained otherwise. The absence of overthrusts and reverse faults and the presence of normal faults striking in every azimuth indicate a condition of tension in all directions. The surface of a dome produced by differential vertical uplift should be characterized by such features. The movements due to normal faulting along the north-south fracture zones are much greater than those along the east-west faults. This is in accordance with the greater tension expressed by east-west (Warner) arching than that existing in the smaller north-south arching.

It is apparent that much of the area under discussion is now elevated high above the Gardens datum. The crest areas of the

Warner arch are from 2,000 to 4,700 feet above that level. Much of the eastern plateau is from 1,500 to 2,000 feet above it. The eastern edge of the plateau is about at the same elevation.

Either absolute uplift of the arch area or a corresponding sinking of the Gardens block and the eastern side of the eastern plateau might produce the arch structure. It seems more reasonable to believe that the crest of the arch was elevated. Depression of an area of at least 2,000 square miles to some 4,700 feet, or more, with the result that the whole unit should remain flat and at uniform elevation, seems incredible. Further than this, the Gardens datum represents not only the characteristic elevation of the Gardens area itself but is repeated in extensive flat areas of basalt north of the Warner Range in Oregon and also south of the range in the plateau east of the Madeline Plains. It therefore appears almost certain that any basalt now above the Gardens datum has been actually lifted to its present position.

Being unable to appeal to any sort of horizontal compressional forces we must conclude that forces acting vertically are responsible for uplifting the greater part of the Warner arch area above the Gardens datum.

That tension exists in all directions at the present time in Surprise Valley is shown by the strikes of the recent escarpments. Each escarpment represents a normal fault, at least when actual fracture has occurred, and therefore extension of surface. From the data presented in figure 28 it is evident that, with strikes in all directions, the margin of Surprise Valley has been areally enlarged in all directions. If a statistical diagram could be prepared for all of the recent escarpments at the Warner Range base it would show more symmetry than the diagram of figure 28, because the whole of the Surprise Valley fault in the valley itself is more nearly meridional than is the ten-mile strip upon which the diagram was based.

If dike strikes bear relation to directions of tension and compression it appears that the direction of greatest tension in the Warner Range area has not always remained the same. In a rough statistical study 90 dikes were taken at random from field-note descriptions and their strikes and lithology noted. It was found that about 40 per cent of the dikes had east-west strikes and that 50 per cent had either east-west strikes or departed less than 10° from that condition. On investigating the lithology it was found that no basalt dikes were included and that a number of these dikes lead to flows in the Cedar-

ville series. The next largest group of strikes was found between north-south and N 20° W, and included 22 per cent of the total count. All of these dikes were basalt excepting two which were rhyolite. Both of the rhyolite dikes, however, were associated with post-basaltic faulting. The third largest group approximated N 60° E, included 17 per cent of the total count, and was all basaltic. The remaining 11 per cent of the dikes had scattering strikes and were mainly andesitic. While dike strikes seemed to occur in varying directions throughout the history of volcanism the direction of most pronounced tension seems to have shifted from north-south to east-west between the andesitic and basaltic eruptions.

Practically nothing is known as to the location of the volcanic vents through which Lower Cedarville andesites reached the surface. Comparatively little is known as to the origin of the Middle Lava layer, excepting that it thickens appreciably toward the south as exposed in the Surprise Valley front. The uppermost layers of the Upper Cedarville, however, are widely exposed in the Warner arch area and around the margins of the Gardens. The lithology of these beds indicates distinctly that the centers of eruption approximated the crest of the Warner arch. Coarse agglomerates in that area grade east and west into finer agglomerates and ultimately into tuff and lake deposits. An extensive lake deposit immediately underlies the basalt in the eastern part of the Gardens and continues southward at least as far as Likely. Fragmental fish bones occur as fossils in exposures along Rattlesnake Cañon north of Alturas. Northwest of Canby, leaf impressions are found in similar beds. At no place in the intervening area are the tuffs and sediments particularly coarse. Followed east into the Warner Range these beds become much coarser. The Cedar Peak area is characterized by agglomerates immediately below the basalt. The agglomerates contain larger fragments both north and south of the Cedar Peak region however. The basalt at the Hays Cañon Range front overlies agglomerate which is somewhat finer than that of the Warner Range. Farther east these agglomerates again grade into tuff and fine sediments. Lake deposits are again found in this area, fossil leaf imprints occurring in great abundance in at least one locality. This generalization, that the vents of uppermost Cedarville time were located along a north-south axis, holds good so far as the writer knows as far north and south as Modoc County extends, and suggests that the direction of major tension in an east-west direction had been established prior to the

deposition of the Warner basalt. Basaltic dikes indicate its prevalence during the period of basaltic accumulation. The orogenic history and evidence from recent escarpments indicates that it has lasted right down to the present time.

Summarizing the preceding paragraphs, it seems that we have no record of any noteworthy horizontal compression in the Warner arch area. A suggestion that the direction of greatest tension has shifted from north-south to east-west in the Cedarville period comes from the study of dike strikes. That east-west tension has been predominant since uppermost Cedarville times is suggested by several lines of evidence, lithologic, stratigraphic, and tectonic. As practically no crustal movement seems to have occurred in the area until after the deposition of the basalt, only the last conditions of tension concern us in regard to the tectonics of the Warner arch. These conditions appear to result from orogenic forces acting along vertical lines.

Grabens.—From a theoretical standpoint it appears unlikely that the Warner arch ever existed as an unbroken feature. The grabens which now divide it into its several parts probably started to form about the time that vertical uplift started. From the standpoint of field observation little can be offered except negative evidence in regard to this question. Had the arch ever existed without the grabens we should expect to find remnants of stream channels and sedimentary deposits so distributed as to suggest former courses across the graben areas. No evidence of this kind was found, excepting the possibility that the distribution of obsidian fragments at the southern end of the Warner Range and Hays Cañon Range might suggest transportation across Surprise Valley. It is certain, however, that the rhyolite at the summit of Cold Peak was not so transported and it is likely that both the rhyolite and the obsidian fragments were distributed prior to either uplift of the range areas or depression of the graben. Thus the time of the initiation of graben sinking remains doubtful.

If we accept the Gardens datum as the original level of the basalt, the graben areas represent just as real downthrow as the range and plateau areas represent real uplift. Where basalt is exposed, both north and south of Goose Lake, it lies some 400 feet below the Gardens datum. Presumably it is still lower beneath the lake itself. In the Pitt River Valley, the southern continuation of the Goose Lake graben, a considerable amount of basalt lies 500 feet and more below the datum. In Surprise Valley exposed basalt lies 300 to 400 feet below

the datum. Negative evidence from wells in Surprise Valley indicates basalt levels at least 800 to 1,200 feet below the datum. The elevation of the basalt is unknown in the center of Long Valley graben. It is exposed at elevations not far above the graben floor and the broad extent and flat surface of that floor suggest deep filling of the central portion. The lowest elevation of the playa floor, according to the Long Valley (Nevada) Quadrangle, is 5,670 feet or some 470 to 670 feet above the datum. High Rock Valley graben is similarly filled by sedimentary deposits but the elevation of these is slightly below the datum so that the basalt must be still lower.

The tendency for lakes to hug steep fault escarpments has been mentioned in connection with Jess Valley, Lake Annie, and the broad playas of Surprise Valley. This fact is not peculiar to the Warner arch area but is exemplified, time and time again, in various parts of the Great Basin, as any good map of that region will show. This is apparently a fact of major importance in regard to the recent tectonics of that area. Many writers have called attention to it.³⁹ Lawson describes, graphically, a similar phenomenon in the Carson Valley of west central Nevada.

The Carson River flows northerly at the base of the mountain and is distributed through an extensive marsh, the waters of which are in places so close to the rocky slope that one may stand upon the latter and throw a stone into them with ease.

Farther on he states:

It is evident from this fact that the relations of mountain and valley are abnormal, and that the abnormality is due to recent depression of the valley floor; since under normal conditions and stability of level, the erosional waste from the mountain front would have long since crowded the streams away from the mountain base, and the lowest part of the valley would be located some miles to the east.

He continues,

It is evident that the displacement was not wholly one of uplift of the mountain block, but that there has been a very pronounced drop of the valley block. It is doubtless true, in accordance with the elastic rebound theory of earthquakes, advanced by Professor H. F. Reid, that both blocks have moved, the mountain block up and the valley block down. But whereas it is difficult to find evidence of the absolute uplift of the mountain block it is clear that the west side of Carson Valley, though its flat floor is certainly due to aggradation, is below base level, and has, therefore, been depressed; and that recently the depression has been more active than aggradation.⁴⁰

³⁹ For discussion and for references to other writers, see Louderback, G. D., *Basin Range structure in the Great Basin*, Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 14, pp. 329-76, pls. 60-68, 2 figs. in text, 1923.

⁴⁰ Lawson, A. C., *Bull. Seis. Soc. Am.*, vol. 2, p. 195, 1912.

Not only in the cases of the examples already cited does this same relationship hold true but it exists, as well, over the whole of the Warner Arch area. Alkali Lake hugs the escarpment at the west of the Long Valley graben. High Rock Lake hugs the escarpment east of High Rock Valley graben. In the area to the north, Alkali Lake, Abert Lake, Summer Lake, and others follow the same rule. Accepting Lawson's conclusions we may add these as examples and state that an abundance of evidence exists that the graben areas of the northwestern Great Basin are actively settling and that the rate of settling is most rapid at the bases of the steepest escarpments.

The recent escarpments in Surprise Valley seem to be associated with the settling of the graben block. This apparently is true for most of the Lake Lahontan Basin as well. Russell's⁴¹ map of Quaternary fault lines and observations on recent escarpments give some notion of the importance of these features. Some of the escarpments are 100 miles in length and displacements as great as 125 feet were noted. Russell notes that the "recency [of the escarpments] is shown by the fact that they commonly occur in Quaternary lacustral sediments and recent alluvial slopes, and form steep slopes of earth and gravel that are but little modified by erosion, and in many instances are bare of vegetation." Despite such facts as these Jones tells us that "Instrumental determination of the elevation of the high-water level over the entire (Lahontan) basin, with the exception of Walker Lake, showed that the shore-lines had not suffered any deformation whatever."⁴² Both lines of observation agree with the evidence in Surprise Valley. The upper shore line of Lake Surprise was surveyed, somewhat roughly, by means of a small field transit and no indication of deformation was noted. The elevation along the Hays Cañon Range front agreed with that of the Warner Range front, and this elevation could be checked for considerable distances up and down the valley. In Surprise Valley, and presumably over the Lahontan Basin as well, the recent escarpments are situated well below the upper shore lines. Displacements upon them have not affected the range blocks, or else the shore lines would tell the story, it being impossible certainly that all the ranges over so large an area could be uplifted uniformly. Recent escarpments, then, seem to be associated only with graben settling, and their widespread occurrence and recency indicate clearly the activity of this process.

⁴¹ Russell, I. C., U. S. Geol. Surv., Monograph 11, pl. 44, and p. 275, 1885.

⁴² Jones, J. C., Carnegie Inst. of Wash., Publ. 352, p. 50, 1926.

Period of faulting.—The only clue from paleontological sources as to the last possible date prior to the deformation expressed by the Warner arch is quite unsatisfactory. In the Upper Cedarville deposits several localities contain leaf imprints which are regarded as Mascall (Upper Middle Miocene) age by Chaney.⁴³ Associated vertebrate remains check this, or at least preclude any earlier age assignment. Later than the deposition of these beds came the period of Warner basalt flows, and still later, the rhyolites. Faulting seems to have started after the rhyolitic period and it has continued down to the present. Thus, while somewhat uncertain, the initiation of the period of faulting was relatively late. Warner arch faulting seemingly fits in well with the conclusions reached by Louderback⁴⁴ as to the period of faulting in the portion of the Great Basin south of the Warner arch region where "faulting is later than the latest recognized Tertiary formations or topographic surfaces," and "The evidence in hand points to a late Pliocene or post-Pliocene time for the beginning of the faulting." Louderback also states that "The greater part of the deformation was completed before the late Pleistocene," a fact which also agrees with the Warner Range because the summit areas are deglaciated.

CONCLUSIONS

Briefly stated some of the major conclusions set forth in this paper are:

1. The lithologic sequence in the area consists of a thick (at least 7,500 feet) andesitic series (Cedarville) composed chiefly of pyroclastic materials, followed by a relatively thin (from at least 600 feet to practically nothing) but widespread flow of basalt (Warner basalt), and later by patch-like accumulations of rhyolite and obsidian.

2. Prior to deformation the bedrock lay concordantly beneath an extensive plain.

3. Deformation, occurring quite recently, and typically resembling that observed elsewhere in the Great Basin, produced the Warner Range, Hays Cañon Range, Goose Lake, Surprise Valley, Long Valley, and other grabens in a wide area called the Warner arch.

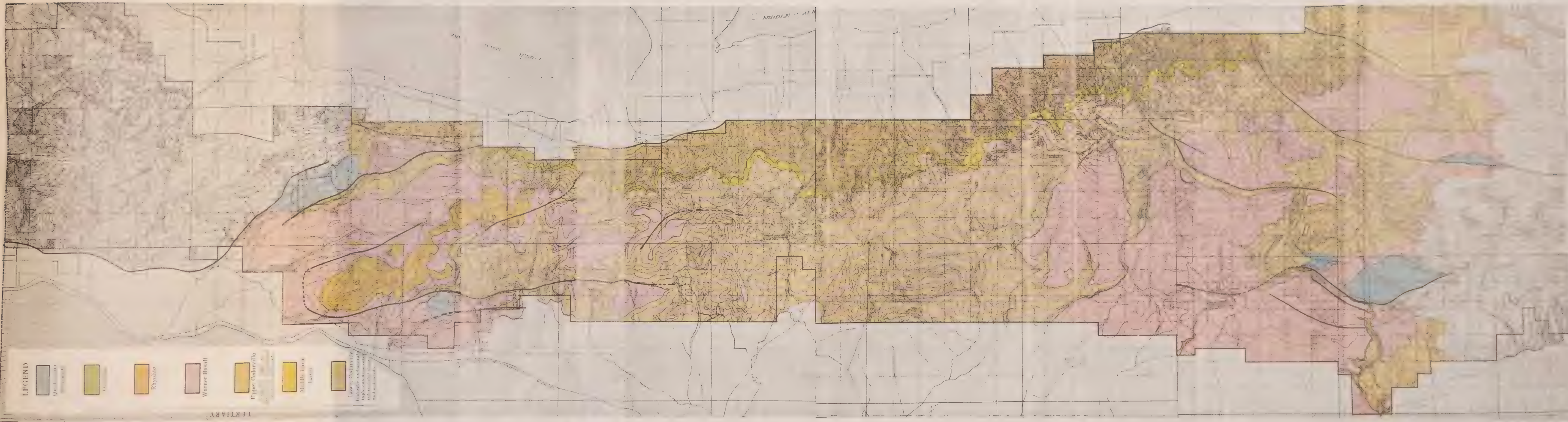
⁴³ Chaney, R. W., Carnegie Inst. of Wash., Publ. 349, p. 32, 1925.

⁴⁴ Louderback, G. D., Period of scarp production in the Great Basin, Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 15, 44 pp., 3 pls., 3 figs. in text, 1924 (conclusions stated on p. 38).

4. Actual uplift of the elevated areas and actual depression of the grabens took place if a plateau area of over 2,000 square miles approximating 5,000 to 5,200 feet in elevation represents the original elevation of the basalt (Gardens datum).

5. No evidence of uplift or depression as a result of horizontally directed compressional forces was noted. Deformation seems explicable only on the basis of differential vertical movements.

6. Displacements taking place in the grabens today seem to be associated with the settling of those areas and not with uplift of adjacent ranges.



GEOLOGICAL MAP OF WARNER MOUNTAINS
Scale approximately 1:100,000

Content interval 50 feet.

Datum is near sea level.

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